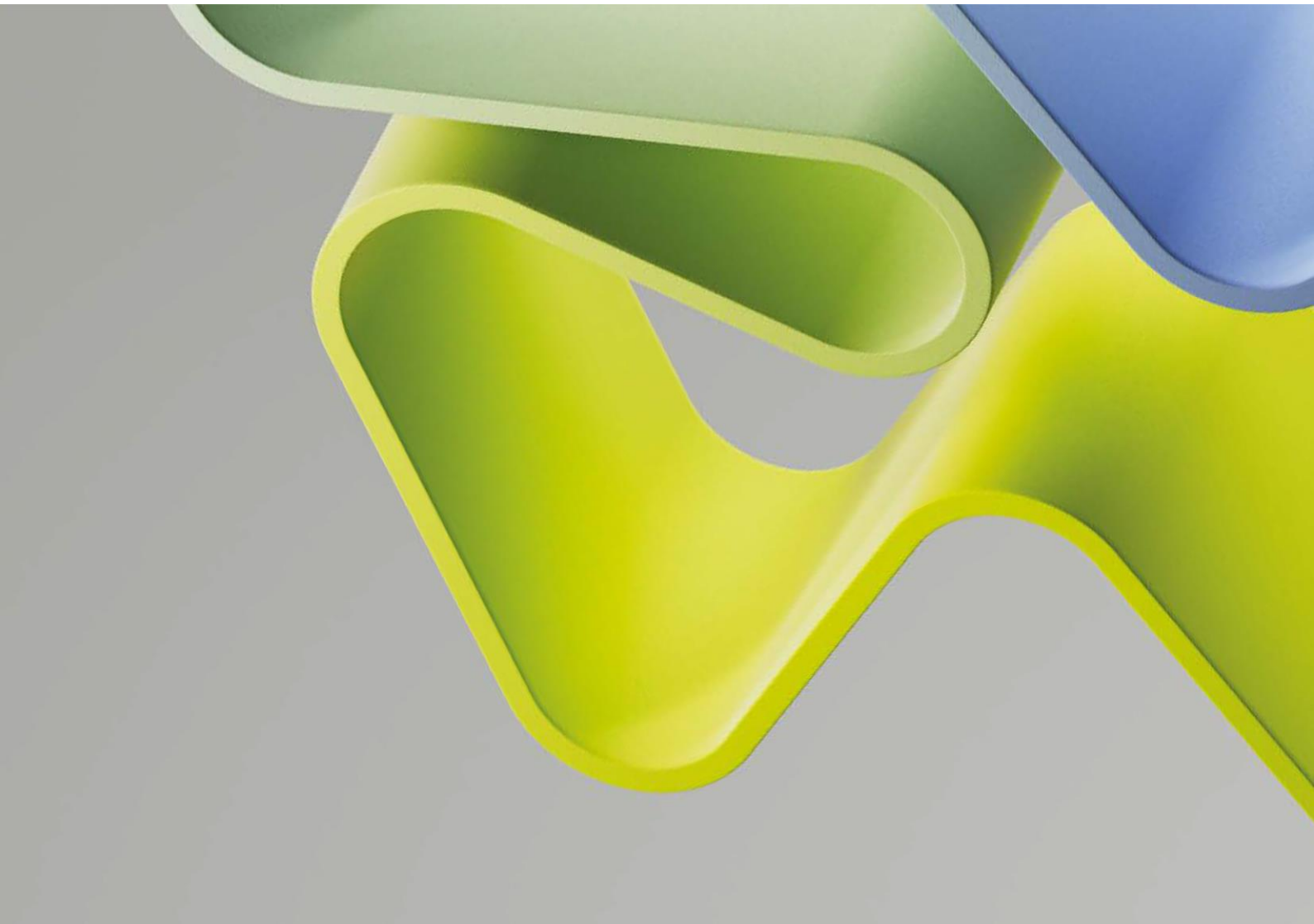
The Research Council of Norway

Evaluation of mathematics, ICT and technology 2023-2025

Impact Cases

March 2025



Introduction

Administrative units participating in the evaluation of research in mathematics, ICT and technology in Norway 2023-2025 were invited to submit case studies documenting the societal impact of their research. In this report the 158 impact cases will be presented in the way they were submitted by the 56 administrative units using the template for impact cases provided by RCN.

Definition

The definition of, and model for, societal impact was derived from the 2021 Research Excellence Framework (REF) in the United Kingdom:

Definition of Societal impact: an effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia.

Impact includes the reduction or prevention of harm, risk, cost or other negative effects.

Academic impacts on research or the advancement of academic knowledge are excluded. Impacts on students, teaching or other activities both within and/or beyond the submitting institution are included.

Impact includes, but is not limited to, an effect on, change or benefit to:

- *the activity, attitude, awareness, behaviour, capacity, opportunity, performance, policy, practice, process or understanding.*
- *of an audience, beneficiary, community, constituency, organisation or individuals.*
- *in any geographic location whether locally, regionally, nationally or internationally.*

Impact case guidelines

Each case study should include sufficiently clear and detailed information to enable the evaluation committee to make judgements based on the information it contains, without making inferences, gathering additional material, following up references or relying on members' prior knowledge.

Timeframes

- The impact must have occurred between 2012 and 2022.
- Some of the underpinning research should have been published in 2012 or later.
- The administrative units were encouraged to prioritise recent cases.

Maximum number of cases per administrative unit:

For up to 10 researchers: one case; for 10 to 30 researchers: two cases; for 30-50 researchers: three cases; for 50-100 researchers: four cases, and up to five cases for units exceeding 100 researchers.

EVALMIT 2023-2025 Antall Impact Cases for hver administrative enhet

Higher Education Institutions	Administrative unit	Number of Impact cases
Østfold University College (HiØF)	Faculty of Computer Science, Engineering and economics	2
Western Norway University of Applied Sciences (HVL)	Faculty of Engineering and Natural Sciences	5
Kristiania University of Applied Sciences	School of Economics, Innovation and Technology	2
Norwegian University of Life Sciences (NMBU)	Faculty of Science and Technology (REALTEK)	4
Norwegian University of Science and Technology (NTNU)	Department of mathematical sciences	5
	Department of Computer Science	4
	Department of Electronic Systems	4
	Department of ICT and Natural Sciences	1
	Department of Information Security and Communication Technology	4
	Department of Engineering Cybernetics – DeptCybernetic	3
	Department of Electric Energy (IEL)	3
	Department of Marine Technology	4
	Department of Mechanical and Industrial Engineering	5
	Department of Architecture and Technology	2
	Department of Civil and Environmental Engineering	4
	Department of Geoscience and Petroleum	3
	Structural Engineering	3
	Department of Manufacturing and Civil Engineering	1
	Department of Energy and Process Engineering	4
Oslo Metropoletan University (OsloMet)	Department of Computer Science	2
	Department of Mechanical, Electronic and Chemical Engineering	2
	Department of Built Environment	2
University of Tromsø - The Artic University of Norway	Department of Computer Science (IFI)	4
	Department for Mathematics and Statistics (IMS)	0
	Department of Computer Technology and Computational Engineering	0
	Department of Automation and Process Engineering	2
	Department of Industrial Technology	1
	Department of electrical engineering	0
	Department of technology and Safety	2

	Department of Building, Energy and Material Technology	0
University of Agder	Faculty of Engineering and Science (TekReal)	3
	Department of Information Systems	3
University of Bergen	Department of Informatics	3
	Department of Mathematics	3
University of Oslo	Department of Informatics	5
	Department of Mathematics	4
Universitetet i Sørøst-Norge (USN)	Department of Science and Industry Systems	2
	Department of Electrical Engineering (IT) and Cybernetics	2
	USN School of Business	2
	Department of Microsystems	3
Universitetet i Sørøst-Norge (USN)	Department of Process, Energy and Environmental Technology	2
University of Stavanger	Department of Mathematics and Physics	2
	Department of Electrical Engineering and Computer Science	3
	Department of Energy and Petroleum Engineering	1
	Department of Mechanical and Structural Engineering and Material Science	3
Research Institutes	**Administrative unit**	**Number of Impact cases**
Institute for Energy Technology (IFE)	Energy and Environmental Technology (ENET)	0
	Human and Organisational Factors (HOF)	0
NORCE Tecnology	NORCE Tecnology	4
Norwegian Computing Center (NR)	Norwegian Computing Center	4
Simula Research Laboratory (SIMULA)	Simula Research Laboratory (SIMULA)	5
SINTEF	SINTEF Community	5
	SINTEF Digital	5
	SINTEF Energy	5
	SINTEF Industry	5
	SINTEF Manufacturing	3
	SINTEF Ocean	3
SUM		**158**

Western Norway University of Applied Sciences, Faculty of Technology, Environmental and Social Sciences - case number 1

Institution: Western Norway University of Applied Sciences (HVL)
Administrative unit: Faculty of Engineering and Natural Sciences (FIN) / from 1.1.2024 Faculty of Technology, Environmental and Social Sciences (FTMS)
Title of case study: Smoldering fires
Period when the underpinning research was undertaken: 2015-2020
Period when staff involved in the underpinning research were employed by the submitting institution: 2015-2020 (see details in Section 2)
Period when the impact occurred: 2019-2023

1. Summary of the impact

Here, we will describe how smoldering fires (see explanation in Section 2) in two industrial cases led to significant economic losses. Both fires occurred locally, in Rogaland county. The cases demonstrated a lack of understanding of smoldering fires in industry, even among fire safety professionals. In both cases, staff members that had participated in an extensive research project on smoldering fires (funded by The Research Council of Norway (RCN)) were called to assist, advise, and give presentations (thus impact). The two industrial fires occurred at a recycling/waste plant and in a storage silo for fishmeal, respectively.

2. Underpinning research

Key research insight: Smoldering fires may seem small and insignificant but can have dramatical consequences both directly and as precursors for (sudden) flaming fires and explosions. This is the simple – but in the general public largely unknown – insight behind the impacts described below.

Our group was able to contribute here, based on an extensive research activity 2015-2020 on smoldering fires (*RCN project 238329 – Emerging Risks from Smoldering Fires*). In addition, a member of our research team had his PhD on smoldering fires (thesis defended 2013), where experiments were carried out and supervision given in our group.

Smoldering involves oxidation directly at the surface of a solid fuel. Dirty smoke is produced, but there are not any flames (flames involve gas-phase oxidation). Temperatures are relatively low, and smoldering is a very persistent type of combustion. An indicative example is smoldering in abandoned coal mines, which can last for many years. Smoldering fires are difficult to detect and difficult to extinguish.

Underpinning research: During projects and periods mentioned above, our group carried out research on several aspects of smoldering fires. Some of these are: Spontaneous transmission from smoldering to flaming fire (see publication 5 in Section 3); various parameters that influence the onset of smoldering (publications 1 and 6); early detection of smoldering fires from emitted aerosols (publication 2); effects of cooling on smoldering fires (publications 3 and 4).

All publications mentioned above (and listed in Section 3) are experimental. The research activity included other experimental designs and modelling of smoldering fires using cellular automata. Most of the experimental studies were carried out with a sample geometry that mimics (at

laboratory scale) industrial storage silos. As will be seen below, one of the impact cases we report is related to an industrial storage silo.

Key researchers:

Sveinung Erland, associate professor, 1st April 2016-2020

Nieves Fernandez Anez, associate professor, March 2018 - 2020. Before joining the staff, she was post.doc. under the RCN project mentioned above May 2016 – February 2018, at collaborating institution Imperial College London.

Vidar Frette, professor, 2015-2020

Bjarne Chr Hagen, associate professor, 2015-2020

Contextual information: The projects and research outlined above concentrate on smoldering as a danger and a risk, that is *uncontrolled* smoldering. Both in modern and older times, *controlled* smoldering has been an important process for modifying materials. A well-known example is production of charcoal from wood, where combustion (smoldering) is maintained at a steady rate by adjusting heat transfer and oxygen access.

3. References to the research

Key output (selected publications) are given below. Quality of the research: The journals below are well-established and of good quality. Furthermore, we have added the number of citations, as obtained from Web of Science 19th February 2024.

1.
E. Villacorta, I. Haraldseid, R. F. Mikalsen, B. C. Hagen, S. Erland, G. Kleppe, U. Krause, and V. Frette:
Onset of smoldering fires in storage silos: Susceptibility to design, scenario, and material parameters.
Fuel 284, 118964 (2021).
DOI: 10.1016/j.fuel.2020.118964 - Open Access
Times cited: 8

2.
N. Bluvshtein, E. Villacorta, C. L. Li, B. C. Hagen, V. Frette, and Y. Rudich:
Early detection of smoldering in silos: Organic material emissions as precursors.
Fire Safety Journal 114, 103009 (2020).
DOI: 10.1016/j.firesaf.2020.103009 - Open Access
Times cited: 10

3.
R. F. Mikalsen, B. C. Hagen, A. Steen-Hansen, U. Krause, and V. Frette:
Extinguishing smoldering fires in wood pellets with water cooling: An experimental study.
Fire Technology 55, 257-284 (2019).

DOI: 10.1007/s10694-018-0789-9
Times cited: 11

4.
R. F. Mikalsen, B. C. Hagen, and V. Frette:
Synchronized smoldering combustion.
EPL (Europhysics Letters) 121, 50002 (2018).
DOI: 10.1209/0295-5075/121/50002 - Open Access
Times cited: 7

5.
B. C. Hagen, V. Frette, G. Kleppe, and B. J. Arntzen:
Transition from smoldering to flaming fire in short cotton samples with asymmetrical boundary conditions.
Fire Safety Journal 71, 69-78 (2015).
DOI: 10.1016/j.firesaf.2014.11.004
Times cited: 21

6.
B. C. Hagen, V. Frette, G. Kleppe, and B. J. Arntzen:
Effects of heat flux scenarios on smoldering in cotton.
Fire Safety Journal 61, 144-159 (2013).
DOI: 10.1016/j.firesaf.2013.08.001
Times cited: 14

4. Details of the impact

We will, for each of the two cases below, describe the event, the connection to our research, and how our research has significantly improved the understanding among fire brigades and companies regarding the handling and prevention of smoldering fires.

Case 1: Fire in waste/recycling plant.

On 22nd September 2022, a fire broke out at company IVAR IKS's recycling plant at Forus, near Stavanger. The fire started in a pile of paper and spread to large parts of the plant. The fire brigade had significant challenges to handle and extinguish the fire, due both to the size of the building and the fact that the fire was a smoldering fire. Such fires are difficult to detect and difficult to extinguish.

The fire led to large damage. Not all actions taken during handling of the fire were optimal. The fact that it is difficult to predict the evolution of smoldering fires has become very clear to our group through the research projects mentioned in Section 2, where several important factors that influence smoldering were investigated.

Following the difficulties the fire brigade had with extinguishment in this case, our college had several requests for presentations on smoldering fire as a phenomenon and its role in the IVAR accident. During fall 2022 and spring 2023, Bjarne Christian Hagen from our team participated at

three conferences/meetings and gave presentations on: Smoldering fire – What is it? How can it be discovered and prevented? The conferences/meetings were:

Fire safety in waste- and recycling plants (November 2022). Arranged by: CTIF-Norge.

The fire safety conference 2023 (March 2023, Tromsø). Arranged by: Brannfaglig fellesorganisasjon.

Seminar (May 2023). Arranged by: Rogaland brannbefalslag.

From discussions in connection with these presentations, it became clear that fire constables, fire safety engineers, and other fire safety professionals do not understand the difference between a smoldering fire and a flaming fire. While a flaming fire can be extinguished by removing oxygen, heat or fuel, a smoldering fire can in most cases only be extinguished through cooling.

Through the research that has been carried out, our group has obtained much knowledge on the differences between smoldering and flaming fires, how each of the can lead to the other, and on factors that affect ignition, evolution, detection, and extinguishment of smoldering fires. We are therefore well prepared to convey this knowledge to fire professionals and students at bachelor and master level.

Case 2: Fire in storage silo for fishmeal.

On 2nd September 2019 a smoldering-like fire broke out in one of the large storage silos at company Karmøy Protein, located 12 km south of Haugesund. This steel silo had diameter 9.5 m and height 35 m. Three indicators of ongoing smoldering fire were: smoke emitted from air valve at silo top, char-like condensates near this valve, and increased temperature in silo as indicated by infra-red imaging.

Smoldering in storage silos like these, with material of organic origin, arises from self-heating: Chemical and biological processes generate heat, and the temperature increases. If left undisturbed, this process will eventually lead to smoldering.

This unwanted temperature buildup will always take place if a sufficiently large amount of material is left undisturbed sufficiently long. A standard precaution is periodic reshuffling of the material, a rule-of-thumb says every 3 months. It turned out that the material that caught fire in the case discussed here, had been left undisturbed for a much longer period.

Self-heating and processes leading to smoldering was an important topic during the research project described in Section 2. Due to the timescales involved, self-heating cannot be directly studied experimentally, only through indirect approaches. Paper 1 in Section 2 represents one such approach, while Paper 2 focuses on precursory processes for smoldering, detected through changes in aerosol production.

As for self-heating, we benefited from collaboration with the group of Professor Ulrich Krause at the University of Magdeburg, Germany, a partner in the project. In particular, they carried out specific experiments on self-healing to support the activity in Haugesund.

During the period the fire brigade used to suppress and extinguish the fire (two weeks), there was a meeting with fire brigade and company, where researchers from our group were invited to inform on smoldering in general and the specific situation. Furthermore, our group carried out an experiment with 1 kg of the relevant fishmeal, using the small-scale silo geometry mentioned in

Section 2. The aim was to characterize the processes initiated at elevated temperatures. Our report on this experiment was included in the final report from the fire brigade.

5. Sources to corroborate the impact

Case 1:

CTIF- Norge: Per Arne Lindvik (perarne@lindviken.no)

BFO: Arnstein Fedøy (arnstein@igneus.no)

Rogaland brannbefalslag: Mari Dirdal <Mari.Dirdal@rogbr.no>

Case 2:

Dag Botnen
Fire Chief, Haugaland Brann og Redning IKS
Dag.Botnen@hbre.no
977 79 444

Western Norway University of Applied Sciences, Faculty of Technology, Environmental and Social Sciences - case number 2

Institution: Western Norway University of Applied Sciences (HVL)
Administrative unit: Faculty of Engineering and Natural Sciences (FIN) / from 1.1.2024 Faculty of Technology, Environmental and Social Sciences (FTMS)
Title of case study: HVL Robotics and the Teknoløft project
Period when the underpinning research was undertaken: 2018-2023
Period when staff involved in the underpinning research were employed by the submitting institution: 2018-2023
Period when the impact occurred: 2018-2023

1. Summary of the impact

The Teknoløft Sogn og Fjordane project is a capacity-building project with the aim of building research capacity in robotics at HVL relevant for regional industry, and to double the funding from the RCN to research-based innovation in the region. Since 2018, the project has collaborated with regional industry to secure more than 160 MNOK in funding for innovation- and collaboration projects in robotics, and has increased the available research capacity from a single researcher in 2018 to a research- and innovation centre "HVL Robotics" counting 5 permanent staff researchers, 2 ongoing PhD-students, 4 post-docs under hiring, as well as an advertised PhD-position.

2. Underpinning research

The Teknoløft-project is based on the recognition that the region Sogn og Fjordane was next to last on the statistics on awarded funding for research-based innovation from the RCN in Norway in 2015, and one of the regions in Norway with the highest number of SMEs (and thus the lowest number of larger companies prone to a higher volume of internal research activities). These regional industry SMEs were in general immature in collaborating with research institutions on research-based innovation projects, and much more prone to do research through purchasing new equipment for their production line.

In 2017, the Teknoløft-project defined the strategic research area "physical human-robot interaction (pHRI)" as the key objective for competence development and increased research capacity for regional industry. The selection was based on the profile of the regional industry in manufacturing, with low production volumes and often tailor-made products, as well as very limited funds for installing complete new automated production lines and more prone to automating smaller parts of the production at the time. This industry profile is very well suited to recent advances in collaborative robots (cobots) – robots automating parts of a production line while working safely along humans. The pHRI research objective of the Teknoløft-project looks one step further into the future of manufacturing (and Industry 4.0) by allowing experienced factory workers to quickly teach these cobots new skills through robot learning and safe interaction technology – without any programming skills. Thus, skilled workers can transfer their expert knowledge to the robot through physical demonstrations and make the low-volume tailor-made production processes more available to automation.

Three key PhD-projects were started to generate expert knowledge in the field of pHRI; one on estimating the motion of skilled workers while collaborating with a robot, one on how the teach the robot new skills from human demonstrations, and one on safe interaction control between robot and human worker. Of the three PhD projects, two has led to novel research results and the PhD-candidates becoming part of the permanent faculty staff. For the last

project, the candidate joined a regional robotics and automation company before completing the PhD project, but has been instrumental in expanding capacity in robot solution providers for the regional industry.

Two key principal scientists have driven the research activities in the project. Associate professor dr. Erik Kyrkjebø started the initiative in 2017, wrote the funding proposal to the research council, and has been project manager of the Teknoløft project since 2018, and is now the research manager and principal scientist for the research centre HVL Robotics from 2023. He has also been principal investigator for a number of innovation projects proposals now successfully funded. Associate professor dr. Martin F. Stølen joined the Teknoløft-project in 2019, and has been instrumental in expanding the research activities to include agricultural robotics for fruit and berry production, and is currently principal investigator of a large collaborative project funded by the RCN on the future of automated fruit and berry production systems in Western Norway. Dr. Stølen has also been the principal investigator on a successful innovation project proposal for regional industry.

The impact of this case, lies in the fact that the capacity building through Teknoløft has been put to use in collaboration with regional industry to secure funding for i) three innovation projects for the industrial sector (RCN - IPN), ii) an international research collaboration project (EEA - POLNOR), iii) a large collaborative project to meet societal and industry-related challenges (RCN - KSP), and iv) an applied research centre HVL Robotics (private funding) (with more than ten researchers, PhD-students and post.docs.) . The current total research activity budget in the region on robotics is more than a 160 million Norwegian kroner for the period from 2018 and towards 2027.

3. References to the research

Key outputs from the research undertaken:

1. Schäle, D.; Stoelen, M. F. & Kyrkjebø, E., Programming Fine Manufacturing Tasks on Collaborative Robots: A Case Study on Industrial Gluing, *Modeling, Identification and Control*, 2023, doi: 10.4173/mic.2023.4.1
2. Ateş, G.; Stoelen, M. F. & Kyrkjebø, E., Exploring human-robot cooperation with gamified user training: a user study on cooperative lifting. Frontiers in Robotics and AI, 2023; 10: 1290104, doi:10.3389/frobt.2023.1290104
3. Ateş, G.; Stoelen, M. F. & Kyrkjebø, E., Force and Gesture-Based Motion Control of Human-Robot Cooperative Lifting Using IMUs, *Proceedings of the 2022 ACM/IEEE International Conference on Human-Robot Interaction*, IEEE Press, 2022, 688–692, doi: 10.1109/HRI53351.2022.9889450
4. Schäle, D.; Stoelen, M. F. & Kyrkjebø, E., Continuous and Incremental Learning in physical Human-Robot Cooperation using Probabilistic Movement Primitives., *IEEE International Conference on Robot and Human Interactive Communication*, 2022, doi: 10.1109/RO-MAN53752.2022.9900547
5. Møgster, J.; Stoelen, M. F. & Kyrkjebø, E., Estimating Robot Body Torque for Two-Handed Cooperative Physical Human-Robot Interaction., *30th IEEE International Conference on Robot and Human Interactive Communication*, 2021, doi: 10.1109/RO-MAN50785.2021.9515470
6. Cupek, R.; Drewniak, M.; Fojcik, M.; Kyrkjebø, E.; Lin, C.-W.; Mrozek, D.; Øvsthus, K. & Ziebinski, A., Autonomous Guided Vehicles for Smart Industries: The state of the art and research challenges., *International Conference on Computational Science 2020*, Springer International Publishing, 2020, doi: 10.1007/978-3-030-50426-7_25

4. Details of the impact

The Teknoløft-project (2018-2024) is a collaborative project between the Western Norway Research Institute (Vestlandsforsking), Vestland Science Park (Kunnskapsparken Vestland) and SINTEF, and funded by the Research Council of Norway (RCN), Vestland county, Sogn og Fjordane savings bank foundation, and regional industry partners. The project aims at building relevant research capacity in the research organizations on robotics (at HVL) and big data (at Vestlandsforsking) for regional industry. The project has a goal of doubling the funding for research-based innovation in the region in the project period 2018 - 2024.

The impact of Teknoløft can be detailed as follows:

i) The project has co-written/collaborated on the following successful proposals for innovation projects for the industrial sector (IPN) for regional industry partners:

- 2020: *Full automation of self-learning production line for prefabricated bathroom modules* for the company Probad/OLS (awarded 10,5 MNOK in funding from the RCN as an IPN project for 2020-2024 with a total project activity of 21 MNOK). Other project partners are Snowlion AS, Prodtex AS and SINTEF Byggforsk. The Teknoløft-project co-wrote the project proposal with emphasis on the research methods, research plan and state-of-the-art review.
- 2021: *DigiSpek – a digital production line for cured ham* for the company Nortura SA (awarded 14,7 MNOK in funding from the RCN as an IPN project in 2022-2025, with a total project activity of 33,3 MNOK). Other project partners are SINTEF Manufacturing AS, Rocketfarm AS, SINTEF Digital AS and Animalia AS. The Teknoløft-project played a smaller part in finalizing the project proposal and research activities.
- 2023: *RobotHandleS – robotic handling of reusable surgical equipment* for the company Retrams AS (awarded 8,6 MNOK in funding from the RCN as an IPN project in 2024-2027, with a total project activity of 17,5 MNOK). Other project partners are Inventas AS and Omron Norge AS. The Teknoløft-project co-wrote the project proposal with emphasis on state-of-the-art analysis, project objectives and planning, work package specifications and budgeting.

A total number of six IPN proposals in robotics has been submitted from the Teknoløft project, and the IPN success rate of the project is 50% on proposals submitted (and 75% for companies awarded funding irrespective of number of attempts).

The long-term impact of these cases has not yet materialized through new production processes, commercial products or patented innovations, due to the recent start of many of the projects. However, the major impact from the Teknoløft project on regional industry is A) *access to funding for strategical research-based innovation activities defined by the companies themselves*, and B) *a maturing of regional industry partners in defining, planning, proposing and running research-based innovation projects*.

ii) The project has collaborated on several proposals for international funding from Horizon Europe, Nordforsk and other sources, and was successful in being awarded funding from the POLNOR program under EEA for the project:

- 2020: *CoBotAGV: Automatied Guided Vehicles integrated with Collaborative Robots for Smart Industry Perspective* together with the Silesian University of Technology and the company AIUT Sp.z o.o in Poland (awarded 6,3 MNOK in funding for HVL from the EEA as a POLNOR project for 2020-2023). The Teknoløft-project co-wrote the work package on

integrating a collaborative robot with a mobile platform and has been responsible for the activity on human-motion cooperation and robot learning in the project.

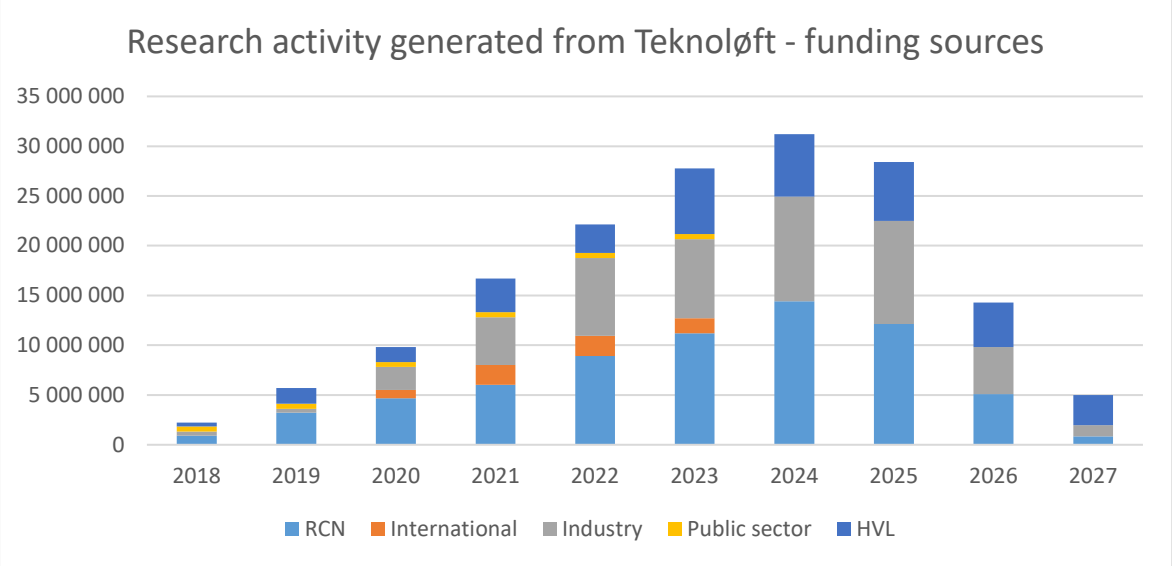
iii) Another strategic activity in the Teknoløft project was to build capacity and knowledge to strengthen the research activities on robotics within HVL. The Teknoløft-project has successfully proposed the following large collaborative project to meet societal and industry-related challenges (KSP):

- 2022: *FutuRaPS: Future Raspberry Production System for Western Norway* where HVL is project responsible (awarded 9,5 MNOK in funding from the RCN as a KSP project for 2023-2027 with a total project activity of 16 MNOK). Regional industry partners are nLink AS, Njøs frukt- og bærsenter AS, Sognabær AS, Sogn frukt og grønt AS and Sparebankstiftinga Sogn og Fjordane.
- 2023: *WILDETECT: Exploring preconditions for an integrated safe and smart traffic environment system – for Wildlife collision avoidance* where SINTEF is project responsible (awarded 9,4 MNOK in funding form the RCN as a KSP project for 2023-2027 with a total project activity of 11 MNOK.

Note that the "FutuRaPS" project was resubmitted two times to the RCN before successful. A total number of 4 KSP proposals in robotics has been submitted from the Teknoløft project, and the KSP success rate of the project is 50% on proposals submitted (and 100% for projects awarded funding irrespective of number of attempts).

iv) The capacity-building activity in the Teknoløft project also aimed at generating long-term impact in the form of a strong research group within robotics at HVL with a continued long-term commitment to support regional industry. The Teknoløft project successfully proposed in 2022 to establish a research and innovation centre "HVL Robotics" from 2023-2027 with a substantial private funding contribution of 7,5 MNOK from Sparebanken Sogn og Fjordane to continue the successful collaboration with regional industry in securing funding for new research-based innovation projects.

In summary, the Teknoløft project has built a research activity relevant for regional industry from a single person in robotics in 2018 to twelve researchers at the end of 2024, and established a research- and innovation centre HVL Robotics to make sure the research capacity will be available for regional industry after the end of the current project. In total, the project has collaborated with regional industry to start new research and innovation projects for a total of 164 MNOK in Western Norway for the period of 2018-2027, for which 67,5 MNOK are contributions from the RCN, and 51 MNOK are own financing from regional companies. The rest of the activities are funded from international funding sources (6,3 MNOK), public sector (3 MNOK) and own financing from HVL (36 MNOK).



5. Sources to corroborate the impact

1. Stein-Asle Øvreboten, CEO, Retrams AS
2. Egil Mundal, CEO, Rocketfarm
3. Anne Karin Hamre, Direktør, Vestlandsforsking (Director, Western Norway Research Institute)
4. Kathrin Jakobsen, Seksjonssjef Forsking, kompetanse og internasjonalisering, Vestland fylkeskommune (Head of section, Research, Knowledge and Internationalization, Vestland County Municipality (own translation))
5. Reiel Haugland, Strategidirektør, Sparebanken Sogn og Fjordane (Director of Strategy, Bank of Sogn og Fjordane County (own translation))
6. Øyvind Midtbø Berge, prodekan regional utvikling og innovasjon, Høgskulen på Vestlandet (Vice-Dean for Innovation and Regional Development, HVL)
7. Trine Lerum, CEO, Lerum AS
8. Hallvard Klakegg, direktør, Sparebankstiftinga Sogn og Fjordane (Director, Bank foundation in County Sogn og Fjordane (own translation))
9. Solveig Willis, R&D Manager, Svanøy Havbruk AS (Svanøy Aquaculture (own translation))
10. Bjørn Lødemel, Dagleg leiar, Sogn og Fjordane Næringsråd (County Sogn og Fjordane Chamber of Commerce and Industry (own translation))

Western Norway University of Applied Sciences, Faculty of Technology, Environmental and Social Sciences - case number 3

Institution: Western Norway University of Applied Sciences (HVL)
Administrative unit: Faculty of Engineering and Science (FIN) / from 1.1.2024 Faculty of Technology, Environmental and Social Sciences (FTMS)
Title of case study: Pilot floating solar plant
Period when the underpinning research was undertaken: 2018-2023
Period when staff involved in the underpinning research were employed by the submitting institution: 2016 to 2020
Period when the impact occurred: 2020-up to now

1. Summary of the impact

Novel floating PV floating (FPV) system designed, developed and installed by the Advanced Nanomaterials for Clean Energy and Health Applications (ANCEHA) research group at HVL and the industrial partner, Current Solar, Norway at the University of Jaffna campus of Kilinochchi, Sri Lanka has made distinct and material contribution to the design of structure, public and policy makers' acceptance in Sri Lanka of floating PVs energy generation. FPV has also contributed to a change the negative opinion on FPVs that was prevailing in Sri Lanka and has now become a show case for future FPV designs and installations. The installed FPV has been mentioned as an example in the governments long term energy generation plan. Based on the positive results from this first and only FPV in Sri Lanka with Norwegian technology, new calls are made by the government for FPV installations in the country. This FPV has also had positive impact on joint partnerships between the Norwegian and Sri Lankan industries. The research conducted has also contributed new knowledge for the research community.

FPV pilot project brought in diverse impacts both at local and global scales. These included impacts related to research, industry, policy, public, economic, and general aspects. The research findings have received global attention as the Global PV magazine reported on the research findings from the facility.

2. Underpinning research

Since, 2012, Advanced Nanomaterials for Clean Energy and Health Applications (ANCEHA) at HVL has been focusing on synthesis and characterization of nanomaterials for emerging solar, hydrogen and energy storage technologies. The research group has been engaged in research collaborations with number of international research institutions, including three Universities in Sri Lanka. In 2018, ANCEHA at HVL initiated efforts to establish a research consortium consisting of Universities and private sector in Norway and Sri Lanka in the field of clean energy technologies. HVL in collaboration with the Norwegian Embassy in Sri Lanka organized visit of 31-member delegation including members from the University sector and 16 clean energy companies from Norway to Sri Lanka. This visit and meetings and the continuation of the collaborative acts paved the way for sanctioning of the first floating solar installation in Sri Lanka by the Sri Lankan authorities. One of the challenges the solar industry face is the lack of vast land area needed for the installation, and floating solar PV is one of the solutions. HVL with our Norwegian partner companies, Current Solar and Rec Solar installed the pilot floating solar PV based on Norwegian floating technology. Current Solar secured funding from Equinor and Innovation Norway for the 46 kW floating solar installation in the lake in Kilinochchi at Engineering campus at University of Jaffna, Sri Lanka.

Floating and mounting structures were designed in Norway and manufactured in Sri Lanka. Composite beams made of glass fibers were used to support the solar panels and high-density polyethylene (HDPE) pipes to provide buoyancy. Usually, the water level reduces continuously in the dry session. Therefore, four anchoring points are set to keep the panel system in the pond surface in order to avoid the structure to dim into the clay when the pond dries completely. The design, the materials, material sizes, and floating structures were developed according to the context in Norway and partly manufactured by local technicians in Sri Lanka. The REC Solar panels were mounted on an innovative zigzag design and made to float in a way, the panels can absorb sunlight both in the morning and evening as opposed to the ground-mounted designs which only receives sunlight in one direction. A reference ground mounted plant was also placed to monitor and compare to provide evidence whether the novel design does produce more than the reference plant in the particular tropical and shallow water context.

Data logger and the sensors are placed to collect the data and the data is being recorded and transmitted to Norway online. Solar irradiation sensors and module temperature sensors are placed on east west orientation. Humidity, water temperature and ambient temperature have also been measured separately. The collected data from this novel floating PV (FPV) system is used to study the performance, reliability, and operational characteristics of the FPV. HVL, Institute for Energy Technology (IFE) and University of Jaffna have been conducting research on this facility.

Resource persons involved:

1. Dhayalan Velauthapillai, Professor, Coordinator, Head of ANCEHA, HVL (2016-now)
2. Inge Vikesdal, CEO, Current Solar, Norway (2018-now)
3. Torgeir Ulset, Business Development Manager, REC Solar, Norway (2018-now)
4. Atputharajah Arulampalam, Professor, University of Jaffna, Sri Lanka (2016-now)
5. Ravirajan Punniamoorthy, Dean, Faculty of Science, University of Jaffna, Sri Lanka (2016-now)
6. Nanthini Nagarajah, PhD Research fellow, HVL (2019-2023)
7. Arnt Fløysand, Professor, HVL (2019-2023)
8. Ahilan Kanagasundaram, Professor, In-charge-of FPV in Kilinochchi, Sri Lanka (2020-now)

3. References to the research

a) Novel floating PV system design from Norway – pv magazine International (pv-magazine.com)
https://www.pv-magazine.com/2022/06/24/novel-floating-pv-system-design-from norway/?fbclid=IwAR3Cyee3Rt3rCvA0s0uJOu_sjrLWA8NfU5xIYz4DHNjysl4XGiWuF-7MUZA

b) Kjeldstad, T. et al. The performance and amphibious operation potential of a new floating photovoltaic technology, Solar Energy, Volume 239, 2022, Pages 242-251, https://doi.org/10.1016/j.solener.2022.04.065

c) Nagarajah, N. The geography of sustainability transition and materiality: grid-tied solar photovoltaic technology in Sri Lanka. Regional Studies, Regional Science Volume 10 (1), Pages 703-722, 2023, https://doi.org/10.1080/21681376.2023.2231508

d) Sri Lanka - Norway float solar power plant | Page 7 | Daily News, National Newspaper article, January 24, 2020

e) Santhakumaran, P. Study of Power Quality Improvement for Grid-Connected Floating PV Plant in Kilinochchi, , 2022, Master Thesis, UiB/HVL https://bora.uib.no/bora-xmlui/bitstream/handle/11250/2999129/Master_thesis--2-.pdf?sequence=1&isAllowed=y

f) Government of Sri Lanka's long term generation expansion plan 2023-2042 document, https://www.ceb.lk/publication-media/planing-documents/121/en, Potential to develop Floating Solar PV Plants (Section 3.4.4.5), 2023

4. Details of the impact

The floating solar pilot project designed, developed and installed by HVL and Current Solar at the University of Jaffna campus of Kilinochchi, Sri Lanka has made distinct and material contribution to the design of structure, public and policy makers' acceptance of this mode of renewable energy generation for its own specific country context, research and academic community and skilled development of domestic work force.

The floating solar pilot project brought in diverse impacts both at local and global scales (reference (a) in Section 3). These included industry and economic impact, policy impact and public impact, (reference (f) in section 3).

Industry and economic impact

The floating solar project established industrial collaboration and partnerships between Norway and Sri Lanka. The implementation of the plant was initiated by Norwegian companies with the support of local companies in Sri Lanka. This also was a platform to exhibit, test and implement a Norwegian designed technology in a dry, tropical context. It was an opportunity for Norwegian solar companies to establish networks and partnerships in global South where abundant solar irradiation exists. This project has also created opportunities for Norwegian solar energy sector to have collaboration with Sri Lankan counterparts. Moreover, the local university benefits economically through sustainable

energy generation through this plant. This off-grid generation saves the university approximately one million Sri Lankan rupees in consumption which otherwise the university will have to pay for the grid-connected supply.

Policy impact

Sri Lankan authorities were reluctant to install Floating PV until this first floating PV installation with Norwegian floating technology was established in Sri Lanka. This demonstration plant has received media publicity and attracted visits from financial institutions, non-governmental organizations, students and public sector officials working on energy and environment. It functions as an exhibit model displaying its potential as an alternative energy solution technology for Sri Lanka

Thus, the demonstration plant appears to appeal to policymakers who initially lacked political will for floating solar to generate renewable energy. This was evidenced in the capacity targets published in their long-term generation expansion plan of 2022-2041, a policy document where the UoJ demonstration plant was referred to as providing research evidence of a viable solution for Sri Lanka paving way for future plans for capacity additions through floating solar plants. (Long term generation expansion plan 2022-2041 https://www.ceb.lk/publication-media/planing-documents/99/en) and (Long term generation expansion plan 2023-2042 https://www.ceb.lk/publication-media/planing-documents/121/en)

Public impact

The initial public resistance to the concept of floating solar was eliminated through the introduction of the demonstration plant at the university premises by way of exhibiting the plant for public viewing, and local data collection that offered answers to their particular concerns. This has brought civil awareness and public convincing about this particular technology. This led to ideas of expanding through floating solar in Sri Lanka for energy generation. When new floating solar projects were called through expression of interests no public objections had been raised. (HRNCET-NORPART Project Journey 2017 – 2021 https://project.jfn.ac.lk/hrncet/)

5. Sources to corroborate the impact (indicative maximum of ten references)

1. Eskedal, Trine Jøranli, Former Ambassador, Norwegian Embassy in Sri Lanka, email: Trine.Joranli.Eskedal@mfa.no
2. Ranjith Sepala, Chairman, Sri Lanka Sustainable Energy Authority, https://lk.linkedin.com/in/ranjith-sepala-175498212
3. Dharmalingam Thanakumar, Senior Advisor Development, Norwegian Embassy in Sri Lanka, email: dthanakumar@gmail.com
4. Prof. Sri Satkunarajah, Vice Chancellor, University of Jaffna, email: srisatku@yahoo.com
5. Professor Priyantha Wijeyatunga, the Senior Secretary of the Asian Developing Bank. https://www.adb.org/contact/wijayatunga-priyantha

6. Eng. K.S. Pirapaharan, Deputy General Manager, Ceylon Electricity Board, Northern Province. Email: ksprabaharan66@gmail.com

Western Norway University of Applied Sciences, Faculty of Technology, Environmental and Social Sciences - case number 4

Institution: Western Norway University of Applied Sciences
Administrative unit: Faculty of Engineering and Natural Sciences (FIN) / from 1.1.2024 Faculty of Technology, Environmental and Social Sciences (FTMS)
Title of case study: Development and application of the ballast water treatment system KBAL
Period when the underpinning research was undertaken: 2011-2023
Period when staff involved in the underpinning research were employed by the submitting institution: 2011-today
Period when the impact occurred: 2011-2023

1. Summary of the impact

In 2004, the International Maritime Organization (IMO) adopted the Ballast Water Management Convention, with the aim to prevent the spread of potentially harmful aquatic organisms. Enforcement in 2017 mandated ships in international traffic to meet specific ballast water standards, leading to widespread adoption of ballast water treatment systems (BWTSs). Knutsen OAS Shipping hence developed KBAL - Knutsen Ballast water, a unique system integrating pressure/vacuum with UV-irradiation. Simultaneously, research focused on water analysis and UV-irradiation, aligning with the development and type-approval process for KBAL. Today KBAL is installed in the Knutsen fleet, including both newbuild ships and retrofitted. KBAL is also sold to external shipping companies and aquaculture companies.

2. Underpinning research

The treatment of ballast water before discharge is important because it prevents the spread of potentially invasive species in local eco-systems through ship's ballast water. The IMO G8 guidelines specify requirements for BWTS that do not use active substances, which includes KBAL. According to the D-2 standard, the discharged ballast water should contain:

- less than 10 viable organisms per m^3 (for organisms $\geq$ 50 µm),
- less than 10 viable organisms per ml (for organisms $\geq$ 10 – < 50 µm),
- less than 1, 250, and 100 colony forming units per 100 ml (for *Vibrio cholerae*, *Escherichia coli*, and intestinal Enterococci, respectively).

Simultaneously, the United States Coast Guard (USCG) introduced its own set of regulations for ballast water management. While there is considerably overlap in the requirements outlined by both sets of legislations, there are also notable differences leading to uncertainty among ship owners and producers of BWTS. The two regulatory bodies specify the same number of permitted organisms that can be discharged via ballast water, but where IMO refers to "viable" organisms, the USCG instead use the word "living". This distinction introduces a crucial contrast: IMO mandates that discharged organisms must be incapable of reproduction and survival (i.e., viability), whereas USCG regulations require that the organisms must be dead (i.e., vitality). This variance poses a challenge for KBAL and other BWTSs utilizing UV-irradiation as a treatment technology. Specifically, low- or medium-pressure UV-lamps impact cell membranes and/or induce DNA damages. Depending on the applied UV-dose, cells can either die or lose their ability to reproduce. Adding to the complexity, cells harbor DNA-repair mechanisms, further complicating the assessment of treatment effectiveness.

The research was carried out at Western Norway University of Applied Sciences (HVL), Faculty of Technology, Environmental and Social Sciences, at campus Haugesund, between 2011 and today. The following projects are included in the impact case:

1. 2011-2014: Grant no. 208653/O70 "Real-time monitoring of ballast water with flow cytometry" was funded by the Research Council of Norway and Knutsen OAS Shipping AS.
2. 2011-2016: PhD-project Ranveig Ottøy Olsen, Public defense: 20.06.2016. Thesis: "*Flow cytometry detection of phytoplankton in UV disinfected water. Implications for ballast water treatment and analysis*". Faculty of Mathematics and Natural Sciences, University of Bergen (UiB) and HVL.
3. 2016-2018: Contract research project "Analysis of ballast water" between Knutsen OAS Shipping AS and HVL.
4. 2017-2023: PhD-project Mathilde Lindivat. Public defense: 17.01.2023. Thesis: "*Development of flow cytometry-based techniques for assessing microbial inactivation after water disinfection and downstream processes*". Faculty of Mathematics and Natural Sciences, UiB and HVL.

Key researchers at HVL:

- Ingunn Alne Hoell
  - Position held: Associate professor (2011-2023), Professor (2023-today)
  - Role in the projects: project leader for project 1 and 3, co-supervisor in project 2, and main supervisor in project 4
- Gunnar Thuestad
  - Position held: Assistant professor (2011-today)
  - Role in the projects: Laboratory responsible and participating in all projects
- Ranveig Ottøy Olsen
  - Position held: PhD-student (2011-2016), Associate professor (2016-today)
  - Role in the projects: PhD-student in project 2, participating in project 1 and 3
- Mathilde Lindivat
  - Position held: PhD-student (2017-2023), Associate professor (2023-today)
  - Role in the projects: PhD-student in project 4, participating in project 3

3. References to the research

1. Olsen, R. O., Hess-Erga, O., Larsen, A., Thuestad, G., Tobiesen, A. and Hoell, I. A. Flow cytometric applicability to evaluate UV inactivation of phytoplankton in marine water samples. *Marine Pollution Bulletin* 96 (2015) 279-285. https://doi.org/10.1016/j.marpolbul.2015.05.012
2. Olsen, R. O., Hoffmann, F., Hess-Erga, O., Larsen, A., Thuestad, G., and Hoell, I. A. Ultraviolet radiation as a ballast water treatment strategy: Inactivation of phytoplankton measured with flow cytometry. *Marine Pollution Bulletin* 103 (2016) 270-275. https://doi.org/10.1016/j.marpolbul.2015.12.008
3. Olsen, R. O., Hess-Erga, O., Larsen, A., Hoffmann, F., Thuestad, G., and Hoell, I. A. Dual staining with CFDA-AM and SYTOX Blue in flow cytometry analysis of UV-irradiated

Tetraselmis suecica to evaluate vitality. *Aquatic Biology*. 25 (2016), 39-52. https://doi.org/10.3354/ab00662

4. Olsen, R. O., Lindivat, M., Larsen, A., Thuestad, G., and Hoell, I. A. Incubation in light versus dark affects the viability of UV irradiated *Tetraselmis suecica* differently. A flow cytometric study. *Marine Pollution Bulletin* 149 (2019), 110528. https://doi.org/10.1016/j.marpolbul.2019.110528
5. Olsen, R. O., Thuestad, G., and Hoell, I. A. Effects on inactivation of *Tetraselmis suecica* following treatment with KBAL: a UV-based ballast water treatment system with an in-line vacuum drop. *Journal of Marine Science and Technology* (2020). https://doi.org/10.1007/s00773-020-00737-2
6. Lindivat, M., Bratbak, G., Larsen, A., Hess-Erga, O.-K., and Hoell, I. A. Flow cytometric analysis of bacterial protein synthesis: monitoring vitality after water treatment. *Frontiers in Microbiology* 12:772651 (2021). https://doi.org/10.3389/fmicb.2021.772651

4. Details of the impact

Below, we present a comprehensive overview of the impact of our research:

Microalgae contribution: We provided a role in the development and optimization of KBAL by introducing the microalgae *Tetracelmis suecica* to challenge water quality. Chosen as an indicator species for the 10-50 µM size class, *T. suecica* demonstrated robustness and its ease of large-scale cultivation made it an ideal candidate. Notably, our recommendation of *T. suecica* was later endorsed when Lundgreen *et. al.* (2019) suggested it as a standard test organism during validation of BWTSs.

- Researchers involved: Hoell, I.A., Thuestad, G., Olsen, R. O., Lindivat, M., Tobiesen, A. and Delacroix. S.
- Dates of impact: 2011-2018

Innovative methodologies: Recognizing the limitations of traditional water analysis methods in evaluating BWTS effectiveness, we focused on developing flow cytometry-based methods for single cell measurements. Flow cytometry allows for rapid analysis of many particles in a short amount of time, has a high sensitivity, and can do multiparametric analysis. Our methodologies specifically targeted the detection of living, damaged, and dead cells, providing a more nuanced and accurate assessment of cell vitality.

- Researchers involved: Hoell, I.A., Olsen, R. O., Thuestad, G., Lindivat, M., Tobiesen, A., Hoffmann, F., Larsen, A., Hess-Erga, O.-K., and Bratbak, G.
- Dates of impact: 2011-2021
- Publication 1-6

Water analysis support: Collaborating with a shipping company, we provided invaluable assistance in water analysis throughout the KBAL development and optimization phases. Our comprehensive approach included growth-based analysis such as most probable number analysis (MPN) and plate count, as well as advanced techniques like fluorescence microscopy and flow cytometry in combination with staining techniques.

- Researchers involved: Thuestad, G., Olsen, R. O., Lindivat, M., and Hoell, I.A.
- Dates of impact: 2011-2018

Deeper insight into UV-irradiation: Our research focused on the assessment of cells exposed to UV-irradiation of various doses. As UV-treatment stands out as one of the widely employed technologies in BWTSs, gaining insights into the UV dose required for effective inactivation is of key significance:

1) it aids BWTS producers in successfully navigating performance tests during type-approval, and 2) it contributes to cost reduction for shipping companies. In addition to evaluating the impact of UV-doses, we also investigated the recovery mechanisms of cells post-treatment, including responses under both light and dark conditions gaining important insight into DNA-repair and regrowth patterns. Notably, our experimental design sought to mimic the conditions of ballast water transport abord ships, ensuring practical relevance and applicability to real-worlds scenarios.

- Researchers involved: Hoell, I.A., Olsen, R. O., Thuestad, G., Lindivat, M., Larsen, A., Hoffmann, F., Tobiesen, A., and Hess-Erga, O.-K.
- Dates of impact: 2011-2020
- Publication 1-5

Alternative application of KBAL-technology: Over the years, the collaboration between the researchers and the industry has expanded, exploring alternative applications of KBAL technology beyond ballast water treatment, such as in aquaculture. Researchers were actively engaged as discussion partners, where their expertise contributed with valuable insights in microbiology and water quality analysis, as well as their previous experience with the KBAL-technology.

- Researchers involved: Thuestad, G., Olsen, R. O., Lindivat, M., and Hoell, I.A.
- Dates of impact: 2016-2023

Environmental impact: Through our collaboration with the shipping company, we successfully assisted towards the type-approval of KBAL by IMO in 2012 and USCG in 2020. Currently operational in numerous vessels in international traffic, KBAL today plays a role in reducing the risk of invasive species in local ecosystems through effective ballast water management.

- Researchers involved: Thuestad, G., Olsen, R. O., Lindivat, M., and Hoell, I.A.
- Dates of impact: IMO – 2012, and USCG – 2020

Other universities/research institutions involved:

- University of Bergen (UiB):
  - Associate professor Friederike Hoffmann (partner in project 1 and main supervisor in project 2)
  - Professor Gunnar Bratbak (participant in project 4)
- NORCE Norwegian Research Centre:
  - Researcher I/research director Aud Larsen (partner in project 1 and co-supervisor in project 4)
- The Norwegian Institute for Water Research (NIVA):
  - Research scientist Ole-Kristian Hess-Erga (partner in project 1, co-supervisor in project 2 and 4)
  - Research scientist and Ballast test facility manager Stephanie Delacroix (partner in project 1)
  - Research scientist August Tobiesen (partner in project 1)

5. Sources to corroborate the impact

Jorunn Seglem
Role: Managing director KBAL, Knutsen group
Contact details: jse@knutsenoas.com

Per Lothe
Role: Special Technical Advisor, Knutsen Technology and Knutsen NYK Carbon Carrier, inventor of KBAL
Contact details: pel@knutsenoas.com, +47 911 74 035

Jan Kåre Helvik
Role: Managing Director, Level Solutions AS (until Dec. 2023), Helvik and colleagues worked with alternative applications of KBAL, e.g. in aquaculture
Contact details: jan.helvik@matre.no, +47 977 90 510

Western Norway University of Applied Sciences, Faculty of Technology, Environmental and Social Sciences - case number 5

Institution: Western Norway University of Applied Science
Administrative unit Faculty of Engineering and Natural Sciences (FIN) / from 1.1.2024 Faculty of Technology, Environmental and Social Sciences (FTMS)
Title of case study: Mobilisation for research-based innovation in the region
Period when the underpinning research was undertaken: 2012 -2023
Period when staff involved in the underpinning research were employed by the submitting institution: 2012 -2023
Period when the impact occurred: 2012 -2023

1. Summary of the impact

This case describes the impact of the work done by the Faculty of Engineering and Natural Sciences on *mobilisation for research-based innovation* in Western Norway in the period 2012-2022. This work consists of a set of activities that have both a *mobilisation component* and a *research component*, which are closely interlinked. Section 2 outlines the mobilisation activities and the underpinning research, focusing on key insights that underpin the impact. Section 3 describes key outputs from the research, and section 4 explains the nature and extent of the impact.

2. Underpinning research

HVL has since 2012 had an ambition to contribute to innovation and regional development in the region of Western Norway. Until 2024 this strategic area was led by the research centre The Mohn Centre for Innovation and Regional Development at the Faculty of Engineering and Natural Sciences (FIN). To contribute to innovation and regional development, the Mohn Centre had three topical areas of activity: research, education, and facilitation for innovation and regional development. A specific aim was to utilise synergies between these three areas.

As a research centre with activities towards teaching (master program in Responsible Innovation and Sustainable Value Creation, PhD program in Responsible Innovation and Regional Development) and facilitation, the work with mobilisation for innovation and regional development was strongly informed by research on the topic. For example, the Mohn centre has in the period 2012-2022 been a key actor in the programmes “Programme for Regional R&D and Innovation (VRI)” (2012 – 2018) and “Programme on Research-based Regional Innovation (FORREGION)“ (2018-today), both regional operationalisations of the VRI/FORREGION program of the Norwegian Research Council which aims to strengthen regional development through mobilisation for more research based innovation in regional industry. In this mobilisation work, a set of instruments such as ‘competence brokering’, pre-projects, R&D meetings and mobility schemes between academia and industry has been utilised by involved staff in order to mobilise both industry and academia towards more collaboration in the region. These activities were also complemented with initiatives towards student entrepreneurship and technology transfer from research activities at the Faculty, resulting in, amongst others, the establishment of Bergen Carbon Solutions and the initiation of the TTO VIS (formerly BTO).

Since 2012, The Mohn Centre has worked annually with approximately 100 companies in the region with little or no prior R&D experience, promoting a greater focus on research-based innovation and facilitating the development of joint R&D projects between industry and academia. In addition, through organisation in regional coalitions, HVL has contributed to heightened awareness of the importance and potential offered by research to regional development. As a participant in the VRI program from its inception (2007) towards the current FORREGION program, HVL has also continuously developed its work on facilitation and mobilisation for innovation and regional development. Most prominently, through the VRI program periods focus from HVL's side shifted from a focus on mobilising organisations and actors in the regions towards research-based innovation, to also stimulating network development, regional innovation system development, and facilitation of regional coalitions. HVL has taken an important role in coordinating activities, strategies and orientation of such collaborative networks in the region, for example, through strong involvement in research-based counselling towards industry facilitators, industry clusters, higher education institutions, incubators, and several industrial networks in the region. Hence, mobilisation for research-based innovation in the region has been conducted towards a) organisations and initiatives on an actor level, and b) networks, coalitions and strategic development on a regional system level.

This work on mobilisation for research-based innovation has been strongly informed by *research* conducted at the Faculty, and particularly the Mohn Centre. The research conducted focused on regional development processes and restructuring of economic activities. This includes topics such as evolution of regional innovation systems, industry clusters, academic spin-offs, entrepreneurship, emergence of new industries, facilitation of network development, innovation policy, and innovation process facilitation. The following key research projects were of particular importance and are included in this impact case:

- *How can policy makers create industrial clusters?* (2013-2014), Norwegian Research Council (#224914)
- *Exploring the role of VRI in regional innovation system formation and new path development* (2014-2016), Norwegian Research Council (#233788)
- *Path development in different regional settings. Regional policy approaches in the global economy* (2015-2018), Norwegian Research Council (#233737)
- *Drivers of regional economic restructuring: Actors, institutions and policy* (2017-2020), Regional Research Fund Vestland (#272054)
- *Unis4vest - The role of universities for sustainable smart specialisation in Vestland* (2021-2024), funded by Regional Research Fund Vestland (#322884)
- *Regional Resilience and Sustainable Industrial Restructuring* (2021-2022), Norwegian Research Council (#316539)

In parallel with these research projects and linked to the strategic orientation discussed above, the following facilitation projects have been key in the work to mobilise for innovation and regional development in the region:

- "VRI 2 Hordaland" - *Regional policy instrument for R&D and innovation*, (2011 – 2013), Norwegian Research Council (#212197)
- "VRI 3 Hordaland" - *Regional policy instrument for R&D and innovation*, (2014 – 2016), Norwegian Research Council
- "MobiFORSK Hordaland" - *Regional policy instrument for R&D and innovation*, (2017-2019), Norwegian Research Council (#269918)

- "MobiFORSK Hordaland" - *Regional policy instrument for R&D and innovation*, (2020), Norwegian Research Council (one year extension of project #269918)
- "FORREGION Vestland" - *Regional policy instrument for R&D and innovation*, (2020 – 2023), Norwegian Research Council (#321960)

Key personnel from the Faculty in the research and mobilisation projects have been:

- Professors: Stig-Erik Jakobsen, Inger Beate Pettersen, Arnt Fløysand, Jarle Aarstad.
- Associate Professors: Jens Kristian Fosse, Øystein Stavø Høvig, Rune Njøs, Svein Gunnar Sjøtun, Rannveig Litlabø
- Senior Lecturer: Øyvind Midtbø Berge

All key personnel have been involved in research and mobilisation activities, except Rannveig Litlabø, who has worked dedicated with mobilisation and facilitation.

3. References to the research

Key outputs from the research described in section 2 includes:

Jakobsen, S-E. Fosse, J.K, Slinning, A. and Våge, A. (2012): Research base competence brokering in Norway: Bridging firms and R&D institutions. In: Alberton, S. (et al): *"The innovation Competence Broker: Bridging firms and R & D institutions".* Mc-Graw Hill, Milano, pp 1-15.

Dahl Fitjar, R., Fosse, J.K., Hauge, E., Isaksen, A., Jakobsen, S-E., Normann, R. og Timmermans, B (2015): Regional satsing for mobilisering og kvalifisering til forskningsbasert innovasjon. (Regional efforts for mobilization and qualification for research based innovation) FoU-rapport 5/2015, Agderforskning.

Aarstad, J., Kvitastein, O.A. and Jakobsen, S.E., 2016. Related and unrelated variety as regional drivers of enterprise productivity and innovation: A multilevel study. *Research Policy*, *45*(4), pp.844-856.

Njøs, R. and Jakobsen, S.E., 2016. Cluster policy and regional development: Scale, scope and renewal. *Regional Studies, Regional Science*, *3*(1), pp.146-169.

Holmen, A.K.T. and Fosse, J.K., 2018. Regional agency and constitution of new paths: A study of agency in early formation of new paths on the west coast of Norway. *European Planning Studies*, 25 (3), 498-515.

Jakobsen, S.E., Uyarra, E., Njøs, R. and Fløysand, A., 2022. Policy action for green restructuring in specialized industrial regions. *European urban and regional studies*, *29*(3), pp.312-331.

4. Details of the impact

Below, we present overview of the impact of our research:

<u>Impact on the innovation capacity of regional firms</u>

In the period 2012-2022, the Faculty has mobilized approximately 100 small- and medium-sized companies (SMEs) in the Western Norway region with little or no prior R&D experience, promoting a greater focus on research-based innovation in the industry and facilitating the development of joint R&D projects between industry and academia. A result of this industry mobilisation is a high

number of applications sent from these companies to funding bodies such as Vestland Regional Research Fund or Norwegian Research Council for projects where the intention is to promote research-based innovation and collaboration between industry actors and academia. In the period 2012-2022, on average and annually, this has resulted in the following number of applications from companies in the region:

- 15-20 funding applications sent from industry actors for research pre-projects
- 4-8 funding applications sent from industry for shorter mobility projects between industry and academia
- 8-10 funding applications sent from industry for research main projects
- 1-2 funding applications sent from industry for funding of industrial PhD projects (doctoral projects in industry)

One particular example of impact is the company Bergen Carbon Solutions AS, which produces carbon raw materials by developing and utilizing an innovative carbon capture and utilization technology. Through the VRI programme and by working with staff from the mobilisation project at the Faculty at HVL from 2016, the company received critical support for a proof-of-concept project which verified the technology and helped the startup attract both public and private support for further development, resulting in upscaling of production and listing on the Euronext Growth stock exchange in 2021.

In addition, the mobilisation activities have also been directed towards larger innovation projects in the region such as industry cluster programs (Innovation Norway), FORREGION Kapasitetsløft projects (Norwegian Research Council), The Centres for Research-based Innovation (SFI) schemes and Centres for Environment-friendly Energy Research (FME).

<u>Impact on regional innovation system and policy development in Western Norway</u>

The work on mobilisation for research-based innovation in the region also focused on further developing the regional innovation system, especially networking between companies and academia, the innovation support system and the long-term strategic orientation of key entities in the system. The role of coordinating initiatives for building and further developing the regional innovation system was taken by the Mohn Centre in collaboration with other key system actors in the region, such as the county administration, industry clusters, and industry facilitators. This is expressed by the Faculty's important role in the development and strategical orientation of several industry clusters in the region (for example Maritime CleanTech, GCE Subsea and NCE Seafood.). It is also associated with efforts to further develop the regional system for technology transfer and incubation (HVL was the founder and main contributor to Nyskapingsparken Incubator, which today is part of VIS), and efforts to develop education programs across higher education institutions in the region in collaboration with industry actors (i.e. Bergen Entrepreneurship Academy).

The underpinning research, together with the mobilisation activity, has also informed the regional innovation policy. Researcher at the Mohn Centre has provided an import part of the knowledge foundation for the regional industry policy of Hordaland County (now a part of Vestland County). Through the research, the importance of collaboration across value chains and between the industry and academia for more research-based innovation has been documented. Such observation has been implemented in the county's strategy document. Recently, the necessity of a green transformation in Vestland, an oil-dependent region, has been emphasized in current research conducted at the Mohn Centre. Insights into creating a place-sensitive policy framework for green transformation have informed the County's latest strategies for sustainable and green industry development.

5. Sources to corroborate the impact

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Kristiania and SEIT: Case number 1

Institution: Kristiania University College
Administrative unit: School of Economics, Innovation and Technology
Title of case study: Be-Insight
Period when the underpinning research was undertaken: 2020-2024
Period when staff involved in the underpinning research were employed by the submitting institution: 2004-2024
Period when the impact occurred: 2020-2024

1. Summary of the impact

Be-Insight is a research project which aims to facilitate automated ticketing ('Be-In, Be-Out'), and help the public transport industry to develop new and better business models. The project sees Kogenta working with Kristiania University College, Ruter AS and Nordland County Council. The project is funded by the Norwegian Research Council. The project remit includes better analysis of passenger behaviour and improved trip flow modelling for the mobility industry – insights which will enable industry players to improve their operation and service offerings. The project uses and combines various technologies to accurately determine the position and movement of mobile phone users, but in a way that never compromises individual privacy.

The impact has led to an AI module to be implemented in Kogenta SDK for public traffic optimization and travel behaviour analysis used by all Ruter metro trains in Oslo and by all SL busses in Stockholm, Sweden.

2. Underpinning research

The purpose of the project is to enable automated ticketing (Be-In, Be-Out) and new business models within public transportation, as well as to improve travel flow and behavior analysis for the mobility industry. This will make the travel experience more frictionless, safer, and fairer, and encourage increased use of environmentally friendly personal transport.

This will be made possible by unique technology. With the sensors in the travelers' mobile phones and other data sources, we will understand the position of the mobile phone very accurately. With this solution, mobility operators will be able to base automated ticketing and gain more insight for further optimization of services.

Travelers will experience this as a "ticket-free" everyday life with more fair pricing and positive environmental and safety consequences. The potential is global.

The most central R&D challenges we expect to encounter in the project:

- Real-time detection of people in various modes of transport
- Minimize the necessary data volume transferred from passengers' mobile phones to the cloud service for accurate detection.
- Determine which sensors should be used and how data from these can be combined to achieve as high accuracy as possible.
- Minimize the amount of work required by services in the cloud service to perform the necessary calculations, thereby facilitating the scaling of the number of users.

The potential for application is enormous. The automatic ticketing, as well as the insight into travel flow and behavior that the innovation represents, is something the market, both nationally and

internationally, has demanded for several years. The composition of project partners with two relevant market actors ensures access to real production environments, as well as testing and outlining new business models that increase the likelihood of success in the pilot and further realization in the market.

3. References to the research

The 5 most relevant articles are:

- Bieler, M., Mukkamala, R. R., & Grønli, T. M. (2022). A context-and trajectory-based destination prediction of public transportation users. ***IEEE Intelligent Transportation Systems Magazine***, *15*(1), 300-317.
- Bieler, M., Skretting, A., Büdinger, P., & Grønli, T. M. (2022). Survey of Automated Fare Collection Solutions in Public Transportation. ***IEEE Transactions on Intelligent Transportation Systems***, *23*(9), 14248-14266.
- Skretting, A., & Grønli, T. M. (2020, December). Baseline for performance prediction of android applications. In *2020* ***IEEE International Conference on Big Data*** *(Big Data)* (pp. 3304-3310). IEEE.
- Büdinger, P., & Grønli, T. M. (2021). Unsupervised data mining on spatial-temporal passenger mobility and survey data during Covid-19. In *2021* ***IEEE International Conference on Big Data*** *(Big Data)* (pp. 4327-4332). IEEE.
- Skretting, A., Grønli, T. M., Majchrzak, T. A., Mateos, C., & Hirsch, M. (2024). Enhanced Transport Mode Recognition on Mobile Devices, **HICSS**

4. Details of the impact

In the future of travel, passengers will enjoy a "ticket free" experience, as well as more reasonable pricing based on an actual number of stops, travel time or travel distance, as opposed to the current pricing structure – which is often perceived as unfair. Our research has shown that a reduction in complexity increases customer satisfaction and increases the number of travellers and trips. Hence, the innovation will lead to more people choosing public transport, which in turn will add sustainability benefits.

'Seamless' is a piece of jargon that's used all too often (and often all too misleadingly) in the world of new technology. In the world of mobility and public transport, however, the 'seamless experience' is a worthwhile aspiration – and it's starting to feel like an achievable one too.

What would a 'seamless public transport experience' feel like? At its simplest, it would be a journey without friction. No confusing fares and routes, no struggle with payment processes. An experience where you leave your own front door and travel smoothly and easily to your destination without any interaction with person or machine, but confident that your journey will be correctly recognised and charged. An experience that is, above all, easier, cheaper and more pleasant than using your own private vehicle to add to the noise and pollution of the city centre.

This project developed a technology to support this vision and has been instrumental in its test and rollout to the public actors in Oslo (Ruter) and Bodø (Reis Norland). It's called 'BIBO' – or 'Be In Be Out' technology. It recognises the presence and subsequent absence of an individual or device from a location or vehicle, collecting metrics that can be applied to charging, route analytics and much more.

Importantly, unlike other ticketing/ monitoring technologies, BIBO doesn't depend solely on Bluetooth and external sensors/ emitters which are highly prone to false positives (are you on the bus, or in an adjacent vehicle, or just walking alongside?) but uses the wide range of inbuilt phone sensors to generate a highly granular picture of passenger activity. And it doesn't depend on the

passenger checking in and checking out – activity that can be surprisingly difficult when (for example) laden down with shopping or herding small children.

Related technologies exist for instance in London, where passengers routinely travel around the network swiping Oyster cards or credit cards at points of entry or egress. But these are not seamless experiences. Referrred to as 'CIBO' (Check In Be Out) or CICO (Check In Check Out) such services require payment instruments to be carried – and sometimes these are forgotten. They require physical interaction at barriers, not always easy for people with disabilities. CICO and CIBO are are not 'frictionless' technologies, and still provide a deterrent to the use of public over private transport which is so vital to sustainable cities. A deterrent too to inclusive engagement with public life by the sight- or mobility-impaired.

'BIBO' is much smarter than this. A mobile app is all that is required for all journeys within the transit system, and without the need for physical checking in and checking out, BIBO reduces congestion at entry and exit points, resulting in faster boarding and disembarking. BIBO also opens up flexible charging options for operators – for example, charging based on the precise distance travelled, the zones crossed and so on. And it gives those operators a mountain of data which they can use to analyse usage patterns, optimise route planning and so on – again, improving the passenger experience and increasing takeup.

The impact of technology in this project is helping urban authorities jump another barrier to the modern sustainable, inclusive city and take another step away from congested, polluted urban life. Predicting people's whereabouts in the future will provide a better understanding of human mobility, thereby having a direct impact on traffic forecasting, urban planning, epidemiological modelling, autonomous driving, and more.

A greater advance of the mobility sector in Norway requires intelligent transport systems and human mobility predictions. This research investigates how insights can inform policymakers on necessary interventions, as well as how future technology can help assess and predict people's mobility. We highlight how technological mobility prediction will supply actors with a more competitive edge. We further bring up the 'fundamental value of privacy', and how the Be-Insight team works solely with anonymised data to hide and protect the identity of mobile phone users. In addition, the research team will only receives aggregated information about the whereabouts of a mobile phone user, never an exact location or other identifying data.

5. Sources to corroborate the impact (indicative maximum of ten references)

- **NRK Radio interview** "Fremtidens billettsystem er billettløse reiser", T.M. Grønli and U. Prøitz, NRK Radio, 2020
- **Industry news communication**, https://www.kogenta.com/news/be-insight/the-future-of-smartphone-battery-conservation-lies-in-intelligent-local-cooperation/ , 2021
- The **newspaper Bodø Nu** published an article on the project by journalist A. Tjemsland's (originally published 06.09.2021): Starter et pilotprosjekt i Bodø (Link expired)
- **Public dissemination**, 2021, Smart betaling for mennesker på farten, https://www.kristiania.no/kunnskap-kristiania/2021/06/smart-betaling-for-mennesker-pa-farten/ (In Norwegian only)
- **Public dissemination,** 2022, In the future, being around other people may prolong the lifetime of your smartphone's battery, https://www.kristiania.no/kunnskap-kristiania/2022/08/in-the-future-being-around-other-people-may-prolong-the-lifetime-of-your-smartphones-battery/

Kristiania and SEIT: Case number 2

Institution: Kristiania University College
Administrative unit: School of Economics, Innovation, and Technology
Title of case study: AI-Based Automated Testing of Web/Enterprise Applications
Period when the underpinning research was undertaken: 2016-2024
Period when staff involved in the underpinning research were employed by the submitting institution: 2016-2024
Period when the impact occurred: 2017-2024

1. Summary of the impact

Software is nowadays impacting most aspects of life, from medical devices, online shopping and the mobile in your pocket, to name a few. But software often has faults. Depending on the system, those faults can lead to death or extreme monetary losses. Goal of this research has been to use AI-techniques to develop automated techniques to detect faults in software systems (in particular for web and enterprise applications). Tens of thousands of faults have been automatically detected with our research prototypes, used by many organizations around the world, like for example Meituan and Volkswagen.

2. Underpinning research

The research has been carried out by the AISE Lab (Artificial Intelligence for Software Engineering), led by Prof. Andrea Arcuri. This particular project was started in 2016 (when he was hired in the current institute), and it is still ongoing. It was first funded by a NFR project (2 postdocs) and currently by an ERC Consolidator Grant (3 postdocs and 4 PhD students). All these people worked on the same tool prototype (called EvoMaster, www.evomaster.org). Each new research output contributed in a software extension to such tool. At the time of writing, **33** research papers have been published, and **16** of those are at Level 2 in the Norwegian system (https://github.com/EMResearch/EvoMaster/blob/master/docs/publications.md).

The research is part of the field of *Search-Based Software Engineering* (SBSE), where Prof. Arcuri is one of the main authorities in such field. The goal of this research was not only to publish research papers, but also provide concrete, usable tool outputs that can be used by practitioners in industry. This is the reason why all the people involved worked on the same tool prototype. Besides direct collaborations with industrial partners (e.g., Meituan, a Chinese e-commerce enterprise with more than 600 million customers, and the car producer Volkswagen), such tool has now been downloaded thousands of times by engineers from all around the world.

The underpinning research is still ongoing. However, the detailed impact description is representative for the status by end 2022.

3. References to the research

The main output of the research is a tool called EvoMaster (www.evomaster.org). This tool is open-source on GitHub, with each release automatically uploaded to Zenodo for long term storage.

33 papers (20 by end 2022) have been published so far (16 at level 2), all available on GitHub: https://github.com/EMResearch/EvoMaster/blob/master/docs/publications.md

The 6 most relevant articles are:

- 2023, M. Zhang, A. Arcuri. *Open Problems in Fuzzing RESTful APIs: A Comparison of Tools*. ACM Transactions on Software Engineering and Methodology (**TOSEM**).

- 2023, M. Zhang, A. Arcuri, Y. Li, Y. Liu, K. Xue. *White-box Fuzzing RPC-based APIs with EvoMaster: An Industrial Case Study*. ACM Transactions on Software Engineering and Methodology (**TOSEM**).
- 2021, A. Arcuri, J.P. Galeotti. *Enhancing Search-Based Testing With Testability Transformations For Existing APIs*. ACM Transactions on Software Engineering and Methodology (**TOSEM**).
- 2021, M. Zhang, A. Arcuri. *Adaptive Hypermutation for Search-Based System Test Generation: A Study on REST APIs with EvoMaster*. ACM Transactions on Software Engineering and Methodology (**TOSEM**).
- 2020, A. Arcuri, J.P. Galeotti. *Handling SQL Databases in Automated System Test Generation*. ACM Transactions on Software Engineering and Methodology (**TOSEM**).
- 2019, A. Arcuri. *RESTful API Automated Test Case Generation with EvoMaster*. ACM Transactions on Software Engineering and Methodology (**TOSEM**).

4. Details of the impact

The direct beneficiaries of this research are engineers and testers in industry, which can use the tool prototype to automatically detect faults in their software systems. However, less faulty software has direct benefits to the users of these systems. Just considering Meituan and Volkswagen, there are hundreds of millions of people which are potentially affected. Furthermore, the tool has been downloaded thousands of times, although we do not have precise statistics of who and how is using it.

The work done with Meituan and Volkswagen is part of so-called “industry-driven” research. As researchers in software engineering, our goal is to solve real problems that engineers in industry face. When we design novel techniques, we need to empirically evaluate them. To do so, we need to have access to real-world case studies. There are several systems that are available on open-source repositories, but unfortunately there are many classes of software that are not common as open-source, like large enterprise systems. To do research on such important topic, there is need of collaborations with companies to access their software systems to use as case study. However, in this kind of collaborations, companies need to get a benefit out of it, otherwise they would have no incentive in participating in these research collaborations. Our research solutions need to be general, and not specific to any particular enterprise. What we do is that we make sure our solution prototypes work on our collaborators’ systems and prioritize them when there are issues or some specific new feature is important for them. As such, these industrial collaborators can immediately use our novel research results to improve their testing processes (which leads to reduced costs and improved code quality of their products), as done in Meituan and Volkswagen.

5. Sources to corroborate the impact

- Report on the use of EvoMaster at Meituan: M. Zhang, A. Arcuri, Y. Li, K Xue, Z Wang, J. Huo, W Huang. *Fuzzing Microservices In Industry: Experience of Applying EvoMaster at Meituan*. https://arxiv.org/abs/2208.03988
- Download statics of EvoMaster: https://tooomm.github.io/github-release-stats/?username=emresearch&repository=EvoMaster (note: these do NOT include people that clone the repository and build the tool locally)
- Engineers reporting issues in the tool: https://github.com/EMResearch/EvoMaster/issues?q=is%3Aissue+ (note: for some of those users, companies where they work can be traced by checking their LinkedIn profiles, if that is linked from their GitHub profiles)

NMBU REALTEK Impact case 1

Institution: Norwegian University of Life Sciences (NMBU)
Administrative unit: Faculty of Science and Technology (REALTEK)
Title of case study: Simulation of brain activity as part of EU Human Brain Project
Period when the underpinning research was undertaken: 2013–2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2013–2022
Period when the impact occurred: 2013–2022

1. Summary of the impact

Biophysics-based simulation of brain activity has become an important part of modern brain research, both basic and clinical [1]. The Computational Neuroscience group at REALTEK has contributed to development of brain simulators in several ways, also as part of the EU Human Brain Project.

2. Underpinning research

One key activity has been the development of the simulator NEST for large-scale simulations of neural networks based on so-called spiking neuron models [4–6]. The contributions from NMBU have been to (i) extend capabilities and improve performance of the simulator NEST for large-scale simulations of neural networks and (ii) develop an ontology for network connectivity specification [4].

Another key activity has been the development of the software LFPy [3] for prediction of electric and magnetic brain signals [2] from brain networks simulators (such as NEST). Here a new version of the software LFPy [3] with extended capabilities has been made, as well as a monograph on the origin of, and how to model electric brain signals [2].

Key researchers

- Professor Hans Ekkehard Plesser
- Professor Gaute T. Einevoll
- Dr. Susanne Kunkel (researcher in project)
- Dr. Torbjørn V. Ness (researcher in project)
- Dr. Geir Halnes (researcher in project)
- Dr. Espen Hagen (researcher in project)
- Stine Vennemo (research software engineer)
- Håkon Mørk (research software engineer)
- Nicolai Haug (research software engineer)

3. References to the research

[1] **G.T. Einevoll**, A. Destexhe, M. Diesmann, S. Grün, V. Jirsa, M. de Kamps, M. Migliore, **T.V. Ness**, **H.E. Plesser**, and F. Schürmann: The scientific case for brain simulations, *Neuron* 102:735-744 (2019)

[2] **G. Halnes**, **T.V. Ness**, S. Næss, **E. Hagen**, K.H. Pettersen, **G.T. Einevoll**: Electric Brain Signals, Cambridge University Press, 2024

[3] **E. Hagen**, S. Næss, **T. V. Ness**, **G.T. Einevoll**: Multimodal modeling of neural network activity: computing LFP, ECoG, EEG and MEG signals with LFPy2.0, *Frontiers in Neuroinformatics* 12:92 (2018); https://doi.org/10.3389/fninf.2018.00092

[4] J. Senk, B. Kriener, M. Djurfeldt, N. Voges, H.-J. Jiang, L. Schüttler, G. Gramelsberger, M. Diesmann, **H. E. Plesser**, and S. J. v Albada. **Connectivity concepts in neuronal network modeling**. *PLOS Comput Biol*, **18**:1-49, 2022. DOI 10.1371/journal.pcbi.1010086

[5] T. Ippen, J. M. Eppler, **H. E. Plesser**, and M. Diesmann. Constructing neuronal network models in massively parallel environments. *Front. Neuroinform.*, **11**:30, 2017. DOI10.3389/fninf.2017.00030.
[6] S. Kunkel, M. Schmidt, J. M. Eppler, **H. E. Plesser**, G. Masumoto, J. Igarashi, S. Ishii, T. Fukai, A. Morrison, M. Diesmann, and M. Helias. Spiking network simulation code for petascale computers. *Front Neuroinform*, **8**:78, 2014. DOI 10.3389/fninf.2014.00078.

4. Details of the impact

The main impact of the project has been in making contributions to the EBRAINS infrastructure (ebrains.eu) in which both NEST and LFPy are integrated. EBRAINS is an open research infrastructure that gathers data, tools and computing facilities for brain-related research. The mission of EBRAINS is to revolutionize how neuroscience is conducted. The main goal of the digital ecosystem that is provided is to enable advances in brain research that translate to innovations in neuroscience, healthcare and technology.

5. Sources to corroborate the impact

- NEST:
  - Website: https://www.nest-simulator.org/
  - 370646 downloads according to https://anaconda.org/conda-forge/nest-simulator (January 2024)
- LFPy:
  - Website: https://lfpy.readthedocs.io/en/latest/
  - 151755 downloads according to https://anaconda.org/conda-forge/lfpy (January 2024)
- Website of EBRAINS: https://ebrains.eu/

NMBU REALTEK Impact case 2

Institution: Norwegian University of Life Sciences (NMBU)
Administrative unit: Faculty of Science and Technology (REALTEK)
Title of case study: Robotic "Meat Factory Cells" for automation of meat processing plants
Period when the underpinning research was undertaken: 2016-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2016-2022
Period when the impact occurred: 2018-2022

1. Summary of the impact

Researchers, within the NMBU REALTEK Robotics Group, have been focussed on alternatives methods to conventional meat processing. Today, meat production lines offer high speed, but have not been automated in a manner that is economically scalable. Therefore, the majority of primary (large cuts) and secondary (smaller cuts and deboning) processing remains manual. In countries like Norway, production volume has a lower priority due to market conditions (small population, low export volume). The Meat Factory Cell (MFC) is therefore a concept which prioritises other characteristics, namely robustness (fault tolerance), flexibility (to raw material variation) and scalability (predictable changes in production volume). The basis for the MFC is robotics combined with innovative smart sensor technology, novel tooling and method development, in addition to artificial intelligence (AI). NMBU has been involved in conceptualising the technique and led its development from concept to industrial prototype.

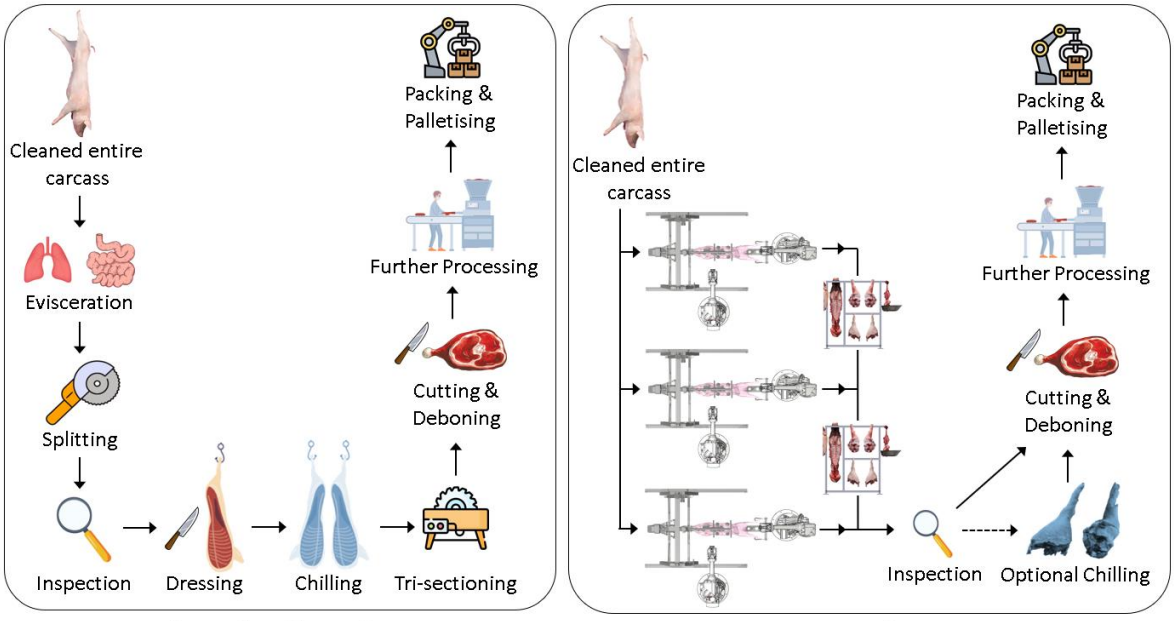

Figure: *An overview of conventional (left) versus Meat Factory Cell (right) approaches. The new approach provides greater opportunities for robustness, flexibility and scalability within future meat processing facilities, through the use of robotics, smart sensors, novel tools and methods, as well as AI. Image source: Alex Mason, NMBU.*

2. Underpinning research

The research was initiated by the Norwegian meat industry, who had a desire to explore automation, particularly new ways of achieving it relevant to national level requirements. This is put into the context that there a few suppliers of holistic (i.e., entire line) automation solutions, all of which make no economic sense in Norway.

The initial research involved understanding of the state-of-art in meat processing (e.g., Ref 1[1]), and development of a novel concept which considered how meat factories, particularly in primary processing, might be built and arranged today considering advancement in technologies and methods (Ref 2). That conceptualisation, which was in animated form, provided the basis for a broad range of stakeholders to discuss how such radical shifts in practise could take place. NMBU engaged in research which considered new methods for primary processing in the future (Ref 3), in addition to the impact of current robotics legislation (Ref 4).

Further development of the MFC system led to revised concepts with greater levels of automation (Ref 5). This was facilitated by research which developed new smart tooling (e.g., Ref 6) which enables feedback regarding knife contact and cutting depth from the cutting process. The work also resulted in an extensive open-access 3D dataset (Ref 7) which led to the development of a new method for robotic meat cutting (Ref 8) reliant on a combination of computed tomography reference data, real-time 3D imagery, and AI approaches. Further work to describe the system has also resulted (Ref 9&10).

Overall, the underpinning research has spanned the conceptualisation of a new approach through to an industrial prototype system (i.e., from TRL[2]1 to ca. TRL5). Several subcomponents (e.g., developed vision-based AI and tooling) have achieved higher TRL. Further, the research has developed into adjacent areas, such as collaborative robotics (Ref 11).

It is noted that dates of the research can be found in Section 3 (references) and Section 4 (externally funded projects).

Key researchers at the administrative unit:

Name	Role	Period Active in Case
Pål Johan From	Professor	2016-18
Alex Mason	Ass. Professor (20%)	2018-19
	Research Professor (80%)	2020-22
Ian Esper	PhD Candidate	2018-22
Dmytro Romanov	PhD Candidate	2020-22
Luis Eduardo Cordova Lopez	Researcher	2020-22
Steven Ross	Researcher	2021
Michaela Pinceková	ERASMUS student	2021
	Engineer	2022

3. References to the research

1. I. Esper, P. J. From, A. Mason "Robotisation and Intelligent Systems in Abattoirs", Trends in Food Science and Technology, vol. 108, pp. 214-222, DOI: 10.1016/j.tifs.2020.11.00, 2021.
2. H. Sverdvik, O. Alvseike, A. Mason, J. Oppen, P. J. From and P. Høines, "Meat Factory Cell: An animation from the Meat 2.0-project", https://youtu.be/6KY8fxLOzQc, 2019.
3. O. Alvseike, M. Prieto, P. H. Bjørnstad, A. Mason, "Intact gastro-intestinal tract removal from pig carcasses in a novel Meat Factory Cell approach", Acta Veterinaria Scandinavica, vol 62, an. 47, DOI: 10.1186/s13028-020-00546-y, 2020.
4. K. Takács, A. Mason, L. E. Cordova-Lopez, M. Alexy, P. Galambos and T. Haidegger, "Current Safety Legislation of Food Processing Smart Robot Systems – The Red Meat Sector", Acta Polytechnica Hungarica, vol. 19, iss. 11, DOI: 10.12700/APH.19.11.2022.11.13, 2022.
5. A. Mason, O. Korostynska, L. E. Cordova-Lopez, I. Esper, D. Romanov, S. Ross, T. Haidegger and K. Takács, "Meat Factory Cell: Assisting meat processors address sustainability in meat production", IEEE 21st International Symposium on Computational Intelligence and Informatics (CINTI 2021), pp. 103-108, DOI: 10.1109/CINTI53070.2021.9668392, 2021.

[1] For references, see Section 3, "References to the research".

[2] Technology Readiness Level.

6. A. Mason, O.Korostynska, L. E. Cordova-Lopez and D. Romanov, "Smart Knife: Integrated Intelligence for Robotic Meat Cutting", IEEE Sensors Journal, DOI: 10.1109/JSEN.2022.3208667, 2022.
7. I. Esper, L. E. Cordova-Lopez, D. Romanov, O. Alvseike, P. J. From and A. Mason, "Pigs: A step by step RGB-D novel pig carcass cutting dataset", Data in Brief, DOI: 10.1016/j.dib.2022.107945, 2022.
8. I. Esper, L. E. Gangsei, L. E. Cordova-Lopez, D. Romanov, P. H. Bjørnstad, O. Alvseike, P. J. From and A. Mason, "3D Model Based Adaptive Cutting System for the Meat Factory Cell: Overcoming Natural Variability", Smart Agricultural Technology, vol. 7, pp. 100388, DOI: 10.1016/j.atech.2023.100388, 2024.
9. A. Mason, T. Haidegger and O. Alvseike, "Time for change: the case of robotic food processing", IEEE Robotics and Automation Magazine, vol. 30, iss. 2, pp. 116-122, DOI: 10.1109/MRA.2023.3266932, 2023.
10. A. Mason, I. Esper, O. Korostynska, L. E. Cordova-Lopez, D. Romanov, M. Pinceková, P. H. Bjørnstad, O. Alvseike, A. Popov, O. Smolkin, M. Manko, L. B. Christensen, K. Takács and T. Haidegger, "RoBUTCHER : A Novel Robotic Meat Factory Cell Platform for Meat Automation", International Journal of Robotics Research, Submitted 21.06.2023, In-press.[3]
11. D. Romanov, O. Korostynska, O. I. Lekang and A. Mason, "Towards human-robot collaboration in meat processing: Challenges and possibilities", Journal of Food Engineering, vol. 331, pp. 111117, DOI: 10.1016/j.jfoodeng.2022.111117, 2022.

4. Details of the impact

The conceptualisation of a new way of arranging meat processing led to several impacts over a short space of time (ca. 4 years), which included externally funded research projects (both national and international), international collaboration, patents, as well as tools, knowledge and data that can be (and is now) applied for the benefit of the meat processing sector.

Externally funded projects

Work toward development of the MFC has come (largely) via three research and/or innovation projects. Those are:

1. **Meat 2.0**[4] (NFR, 256266, 2016-2020). Led by Nortura SA, with the goal of conceptualising an alternative method of slaughter. The project, importantly, led to a visual conceptualisation of the MFC. This was the main contribution of researchers at NMBU REALTEK, which enabled both veterinarians and engineers to work in parallel: to address the legislative challenges posed by new methodologies, as well as the technical challenges (i.e., how to make it work).
2. **MeaTable**[5] (NFR, 281234, 2018-22). Led by NMBU (Prof. Alex Mason), this project directly followed Meat 2.0, attempting to realise the MFC concept. This project led to development of a new strategy for meat cutting (in pork), a 3D-based dataset to facilitate AI development, new approaches to gripping and handling of meat using vacuum systems, as well as a first physical prototype MFC.
3. **RoBUTCHER**[6] (EC, 871631, 2020-22). Led by NMBU (Prof. Alex Mason), this project continued the work of MeaTable, enabling demonstration of an AI-driven MFC able to autonomously perform several primal cutting actions on entire pork carcasses. This was enabled by a novel system approach, newly developed tools, novel approaches to processing 3D data using AI, as well as comparison the results versus human butchers. Legislative aspects (both robotics and meat safety) were considered, which in addition enabled consideration of the approach social

[3] This article is in-press at the time of submission. A PDF copy of the last submitted manuscript can be provided upon request.
[4] https://prosjektbanken.forskningsradet.no/en/project/FORISS/256266
[5] https://prosjektbanken.forskningsradet.no/en/project/FORISS/281234
[6] https://cordis.europa.eu/article/id/447898-towards-sustainability-in-meat-production

performance and impact. Further, this project followed on from MeaTable consideration of collaborative robotics, a topic that is likely to have great future impact for the meat and food processing sector.

International Collaboration

The projects noted above have inherently included international collaboration, which has included knowledge centres, Universities, suppliers and end users. Those include:

- Ciklum LLC, Kyiv, Ukraine (Software supplier)
- Danish Technological Institute, Taastrup, Denmark (Research Institution)
- FACCSA SA,Malaga, Spain (End user)
- Byemotion, Västerås, Sweden (Software supplier)
- Obuda University, Budapest, Hungary (Research & Education Institution)
- Max Rubner Institute, Kulmbach, Germany (Research Institution)

Knowledge and Training

During the course of the research, a number of events have been organised to educate and expose students to the research. Those events include workshops in Norway and Hungary, in addition to a 3-day agrifood robotics training school and a virtual event which included students attending the National Technical University of Ukraine. Those events took place in 2021 and 2022. Overall, these events have included students High School, Bachelor, Master and PhD level. Further, the research involved an ERASMUS placement, with Michaela Pinceková (Slovakia) joining the research team for 6 months initially, and then for a further 12 months as an engineer.

PhD Candidates[7]

The research undertaken to date has included 2 PhD candidates who have actively contributed to scientific knowledge through open-access publication of research findings and data.

- Ian Esper (2018-2022). Thesis title: *Intelligent Cutting in Meat Processing: Integrating CT-scans and RGB-D Imaging with Artificial Intelligence in a Framework to Overcome Natural Variability*
- Dmytro Romanov (2020-2022). Tentative thesis title: *Investigation and application of human-robot collaboration on meat processing lines*

Patents

A. Mason, O. Korostynska and L. E. Cordova-Lopez, "Sensorised Knife-Blade Cutting System", UK Patent Application No. 2108679.8, *Filed* 17.06.2021.

This patent relates to the research described in Ref 6, which is a novel robotic tool to improve feedback and control during meat cutting. This novel tool overcomes challenges experienced using vision systems alone for this activity, where error in depth perception leads to low quality cuts.

Applied knowledge

The outcome of the system has provided a significant contribution for the meat sector. It has advanced thinking and understanding of high-level processes (arrangement of factories and processes), as well as developed and demonstrated advanced systems which have previously eluded the industrial robotics domain. The work pushed forward the frontier for robotics and automation research within the food sector and has allowed end users to see what is becoming possible when combining robotics, AI and advanced sensor systems. Open datasets have also enabled researchers in Korea, Australia, New Zealand, United States and Europe to work on optimising automation techniques, without having to collect their own data. All of the projects have worked closely with industry, with the initial need coming from the sector itself. The MFC, as a system, has been trialled to the industrial prototype level (i.e., it has been used in a pilot scale industrial environment). Several components developed by collaborative partners have reached the market; those developed at NMBU are in the process of commercialisation (e.g., see previous patent) as of end 2022.

[7] It is noted that the PhD candidates work spans beyond 2022.

5. Sources to corroborate the impact

RoBUTCHER project website, https://robutcher.eu/.

Neste generasjons slakteri: Robotene tar over, Tekna, https://www.tekna.no/magasinet/neste-generasjons-slakteri-robotene-tar-over/, December 2023.

Towards sustainability in meat production, EC Cordis, https://cordis.europa.eu/article/id/447898-towards-sustainability-in-meat-production, November 2023.

Wir und das tier - Ein schlachthausmelodram, IMDb, https://www.imdb.com/title/tt27606209, November 2023.

Like muligheter i slakteribransjen, Mat og Marked, https://matogmarked.no/forskning-nyheter/2022/muligheter-i-slakteribransjen, June 2022.

Interview with Alex Mason (RoBUTCHER), agROBOfood, https://old.agrobofood.eu/newsletter17-interview/, November 2021.

Robutcher - framtidas svinslakting, Svin, https://svineportalen.no/robutcher-framtidas-svineslakting/, June 2021.

Den nye slakteren, Nationen, https://www.nationen.no/naering/den-nye-slakteren/, October 2020.

NMBU REALTEK Impact case 3

Institution: Norwegian University of Life Sciences (NMBU)
Administrative unit: Faculty of Science and Technology (REALTEK)
Title of case study: Biodiesel Production for aviation (BIOPROAV)
Period when the underpinning research was undertaken: 2014-2015
Period when staff involved in the underpinning research were employed by the submitting institution: 2014-2017
Period when the impact occurred: 2014-2022

1. Summary of the impact

The production of biodiesel from renewable sources using non edible jojoba oil as feedstock while employing a renewable based waste related catalysts have had a significant impact and contribution in reducing the cost for productions of a renewable fuel as well as developing a new methodology to produce high value by products (jojobyl alcohols) which have shown great potential to be used as adjuvants for vaccines against virus.

Furthermore, the technoeconomic analysis has shown that the new solution has a potential to be studied forwarded with the possibility to be a commercial alternative, therefore proof of concept applications and demonstrator units will be built based on this project.

2. Underpinning research

The key research of the work was to develop a new process technology to produce sustainable fuel using a non-edible source of oil while simultaneously utilizing a renewable bio based catalytic material produced from waste sources. This was achieved by producing biodiesel (sustainable fuel)l from jojoba oil obtained from jojoba seeds (non-edible source of oil) while using Calcium Oxide (CaO) as catalysts produce from mussel shells (waste source from the seashell industry).

The underpinning research was carried out by Professor Marchetti and his group, in cooperation with Professor Aracil and his group from Spain. This work has se the foundation for the utilisation of waste material for development of catalytic process for biofuel production. The utilization and valorisation of the by products stream was not the key element at the moment. It become clearer that the by products (long carbon-based alcohols) were a key element for the productions of vaccines with a high potential market.

This project has led to a development of new process to produce not only biofuel but also bio-based chemicals to be use within the pharmaceutical industry. The researched carried out at the physics department at REALTEK, NMBU, has allowed new understanding of the process, new insight of the technology as well as new developments that have been materialized into granted projects (EU), project proposal (NFR, EU, EEA), as well as in new ideas for new funding calls (ERC Synergy). In addition, the work has allowed several publications since 2014 (18 paper in international journals, 21 participations in international meetings), and has allowed 4 PhD students to get their degree and 1 is currently finalizing his work.

Key researchers:

- Professor Dr. Jorge Mario Marchetti
- Dr. Mangesh Avhad (PhD student during the project)
- Dr. Marcos Snachez (Visiting researcher)

- Dr. Marta Serrano (Visiting Researcher)

3. References to the research

1. "Enzymatic production of sustainable jojoba fatty alcohols: A Biorefinery approach" A. Bouaid, N. Tardon, O. Hurtado, J.M. Marchetti. Food and Bioproducts Processing 139, (2023), 89-97
2. "Optimization of the esterification reaction of free fatty acids present in waste salmon oil" J.M. Marchetti. Biofuel, Bioproducts and Biorefining. 16(5), (2022), 1297-1303
3. "Optimization of the enzymatic butanolysis of jatropha oil for biodiesel production using Eversa". H. Acherki, A. Bouaid, J.M. Marchetti. Biofuels, Bioproducts and Biorefining. 16, (2022), 219-227.
4. "Enhancing Biodiesel Production using green glycerol enriched calcium oxide catalyst: an Optimization study". M.R., Avhad, L.S., Gangurde, M., Sánchez, A., Bouaid, J., Aracil, M., Martinez, J.M., Marchetti. Catalysis Letters. 148(4), (2018), 1169-1180
5. "Modeling chemical kinetics of avocado oil ethanolysis catalyzed by solid glycerol-enriched calcium oxide". M.R. Avhad, M. Sánchez, M. Martínez, J. Aracil, J.M. Marchetti. Energy Conversion and Management. 126, (2016), 1168-1177.
6. "Enhancement of the jojobyl alcohols and biodiesel production using a renewable catalyst in a pressurized reactor". M. Sánchez, M.R. Avhad, J.M. Marchetti, M. Martínez, J. Aracil. Energy Conversion and Management. 126, (2016), 1047-1053.

4. Details of the impact

The development and optimization of new catalytic material, new process and the discover of the high value of the by product had a significant impact on the number of cooperation, publications, projects and knowledge generated.

Projects:

1) Maria Skłodowska-Curie Actions. Staff Exchange. "Unrevealing the mechanisms involved when producing biodiesel from waste oil using a combined experimental and theoretical methodology" (UNPRECEDENTED). Coordinator of the project. (January 2023- December 2026). Funding: Euro: 174.800
2) Marie Skłodowska-Curie Individual Fellowships. Proposal number: 101024550, Proposal acronym: AlgalBB. "Development of Cost-Effective Process for Phyco-Remediation of Dairy Wastewater and Valorization of Algal Biomass for Production of Biofuel and Biochemical: A Sustainable Approach towards Bio-Refinery". Supervisor for candidate Suvidha Gupta. 2-year grant, funding: Euro: 214.158,72. (May 2023-May 2025)
3) Capacity building in Renewable Energy Research and Education in Ethiopia (ReREd) financed by NORHED-II - Norhed II NMBU Programme 2021-2026 (QZA-21/0182 (Project 5)". Responsible for the supervisor of 1 PhD student and 1 Post-doctoral fellowship. Funding: KNOK 19.197.
4) NMBU internal project "Biofuel production from fish waste using data mining and data modeling for optimal catalyst selection". I am the project leader and main responsible for the PhD positions associate it with it. (2021-2024)Funding: KNOK 2.000.
5) Raices Program Project: "Development of a New Technology for Biodiesel Production using Waste Raw Material. Experimental and Theoretical design of catalyst". Program "RAICES" Argentina Ministry of Science and Technology. Project Leader for Faculty of Science and Technology, Norwegian University of Life. Sciences. (October 2017-September 2020). Funding: KNOK 1.000.

6) NORAD-NORHED Project. “Research and Capacity Building in Clean and Renewable Bioenergy Production and Utilization in Ethiopia”. Project Responsible for the Department of Mathematical Science and Technology for the Norwegian University of Life Sciences. (August 2015-August 2020) Funding: KNOK 10.000.

Doctoral Candidates:

- Mangesh Avhad (2014-2017)
- Marcos Sanchez (2011-2015)
- Marta Serrano (2011-2016)
- Yadessa Keneni (2015-2020)
- Iver Hvidsten (2021-2023)
- Getachew Demie (2021-2024)

International Cooperation

The project was an international cooperation among Spain and Norway. It has allowed a great synergy that it is continue today among the research groups. In addition, it has allowed the development of new international partnerships with Portugal, Argentina, UK, Sweden, Denmark, Ethiopia, among others. These cooperations have permitted new projects applications that have been submitted and funded and new proposal that will be submitted to ERC Synergy as well as SFI.

Patents
No patents

Applied Knowledge

The outcome of the projects has provided a significant contribution in the basic understanding of new more efficient and renewable process to produce bio-based fuel (biodiesel) while simultaneously produce long carbon-based alcohols that have shown outstanding potential for its use as adjuvant sin vaccines against infectious diseases.

The outcome of the project has allowed the synergy work among physics, material science, processing engineering, system processing design, catalysis, bioenergy as well as immunology and pharmaceutical with satisfactory results and high potential in all these fields.

5. Sources to corroborate the impact

Dr. Abderrahim Bouaid, Universidad Complutense de Madrid, Spain.
Dr. Alfredo Juan, Universidad Nacional del Sur, Argentina.
Dr. Joao Gomes, ISEL, Portugal.

NMBU REALTEK Impact case 4

Institution: Norwegian University of Life Sciences (NMBU)
Administrative unit: Faculty of Science and Technology (REALTEK)
Title of case study: Spectroscopy and machine learning for bioprocess development
Period when the underpinning research was undertaken: 2012-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2010-2022
Period when the impact occurred: 2012-2022

2. Summary of the impact

Since its inception in 2010, BioSpec has thrived in a multidisciplinary environment, dedicating its focus to advancing bioprocess technology with the main focus on fermentation using filamentous fungi, yeast, algae and bacteria for the production of high-value chemicals. The group has made an important contribution to the development of industrial fungal fermentation as a part of a biorefinery concept in Norway and internationally.

The group has successfully implemented spectroscopic monitoring across all scales, ranging from sub-cellular and cellular levels to the population level, and use these spectroscopic sensors in at-line and online settings. Furthermore, a comprehensive platform has been established to facilitate the seamless execution of microbial processes, spanning from micro- to large-scale volumes. With cutting-edge artificial intelligence, we now possess the capability to create digital versions of microbial processes. These digital models empower us to monitor, optimize, and control these intricate bioprocesses efficiently, marking a significant stride towards precision and innovation in our endeavors. BioSpec has published around 150 scientific publications in this area, coordinated and been partner of around 20 NFR and EU projects within this area.

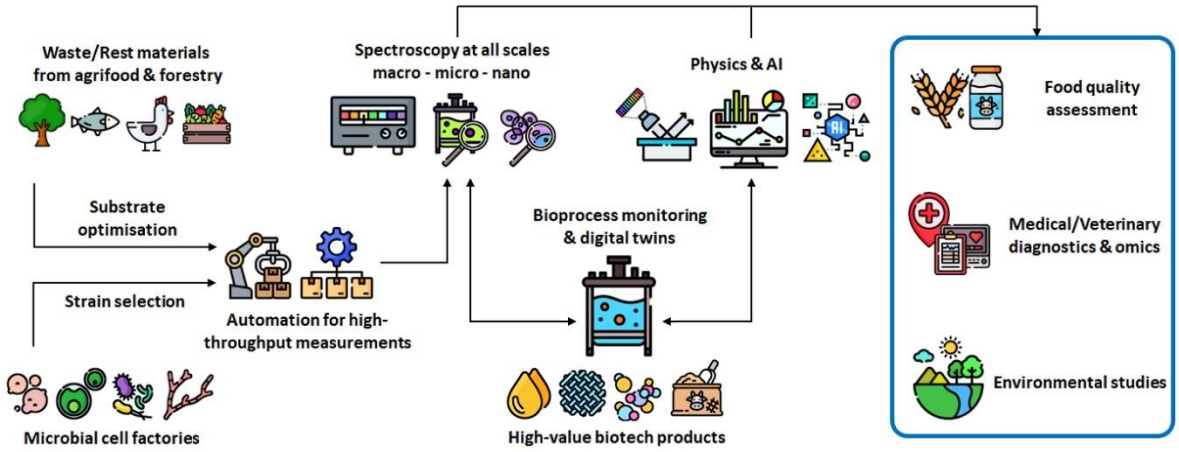

Figure: Core research at BioSpec (left) and spin-off research (right, in the blue field)

2. Underpinning research

1. **Advancements in Spectroscopic Monitoring:** The BioSpec team has been at the forefront of developing state-of-the-art spectroscopic approaches for monitoring fermentation at

every scale. This encompasses the establishment of cutting-edge microspectroscopic and nanospectroscopic techniques. In addition, we have pioneered high-throughput spectroscopic monitoring of microbial biomass, employing advanced robotics for precise sample handling. This innovative approach enables a comprehensive biochemical fingerprinting of biomass.

2. **Innovative Data Analysis Tools for Cell Spectroscopy:** Our commitment to excellence extends to the development of advanced data analytical tools tailored for cell spectroscopy. Through the integration of artificial intelligence, we have created tools for the analysis of spectral data. Notably, we have achieved a significant milestone with the introduction of infrared diffraction tomography—a groundbreaking method for three-dimensional analysis of cell chemistry, representing a remarkable leap in our analytical capabilities.

3. **Tailored Development of Microbial Bioprocesses:** BioSpec has dedicated significant efforts to the development of microbial bioprocess technology, in particular fungal fermentation. Our multidisciplinary team collaborates to design, develop and optimize fermentation processes, and to develop downstream processes and biomass fractionation. This commitment to precision and customization sets BioSpec apart in the field of microbial bioprocessing. The group pioneered in Norway fungal fermentation using various low-cost substrates to produce single cell oils and amino polysaccharides for various applications. It contributed to advancing knowledge on metabolic versatility of non-conventional Mucoromycota filamentous fungi and yeast.

4. **Bioprospecting of microorganisms for biotechnology:** BioSpec has been involved in exploring and discovering microorganisms with unique properties or capabilities that can be utilized in various biotechnological applications and bioprocesses. This involves the analysis of microorganisms from diverse environments, such as soil, water, and extreme habitats, to identify potential candidates for industrial use. For this, BioSpec utilizes established by the group unique high-throughput spectroscopic techniques combined with microcultivation.

Names of the key researchers and what positions they held at the administrative unit at the time of the research:

- Dr. Achim Kohler, Prof. in physics, since 1st of December 2010
- Dr. Volha Shapaval, Assoc. Prof. in bioprocess technology, since 1st of January 2015
- Dr. Valeria Tafintseva, Researcher in data science, from 16th of May 2014 to 7th of November 2023
- Dr. Boris Zimmermann, Res. Prof. in chemistry, since 1st of September 2013
- Dr. Kristin Tøndel, Prof. in data science, started at REALTEK from 15th of April 2014 in a 20% position, since 1st of July 2017 100% position

3. References to the research

Deep learning-enabled Inference of 3D molecular absorption distribution of biological cells from IR spectra
Communications Chemistry (2022)
DOI: 10.1038/s42004-022-00792-3
Link

Assessment of biotechnologically important filamentous fungal biomass by Fourier transform Raman spectroscopy
International Journal of Molecular Sciences (2021)
DOI: 10.3390/ijms22136710
Link

A modular liquid sample handling robot for high-throughput Fourier transform infrared spectroscopy
Advances in reconfigurable mechanisms and robots II (2016)
DOI: 10.1007/978-3-319-23327-7_66
Link

A fully automated robot for the preparation of fungal samples for FTIR spectroscopy using deep learning
IEEE Access (2019)
DOI: 10.1109/ACCESS.2019.2941704
Link

Microcultivation and FTIR spectroscopy-based screening revealed a nutrient-induced co-production of high-value metabolites in oleaginous Mucoromycota fungi
PloS one (2020)
DOI: 10.1371/journal.pone.0234870
Link

High-throughput screening of Mucoromycota fungi for production of low-and high-value lipids
Biotechnology for biofuels (2018)
DOI: 10.1186/s13068-018-1070-7
Link

4. Details of the impact

Biospec started to work on the use of spectroscopy and data science for characterization of microorganisms and other biological systems more than 10 years ago. In a Research for SME project under the EU program FP7, BioSpec developed the first version of a high-throughput and automated system for preparation of microbial biomass after growth for vibrational spectroscopy. This system allows performing development and optimization of fermentation processes on micro-scale.

Further, BioSpec established spectroscopy-based online monitoring of fermentation for pilot scale using an in-house built bypass system. This work was in the following years extended by a broad portfolio of research and development projects, where both the high-throughput automated platform and the on-line monitoring system were used for bioprocess development. The further development of the platform in following projects and research projects for bioprocess development allowed the BioSpec group to have a considerable impact on Norwegian bioprocess development.

Externally funded projects:
The impact on the national and international bioprocess development is manifested by the broad portfolio of research funding BioSpec was able to acquire during the last 10 year involving the participation in three SFIs/FMEs, the coordination of a Research Innovation action under Horizon

2020 and the coordination of and participation in a large number of research and development projects. Some examples are:

FABS (NFR-KOMMERSFORSK 337443, Link), PHOTONFOOD (H2020-ICT-2020-2 101016444, Link), DigiFoods (NFR-SFI-309259, Link), BYPROVALUE (NFR-MATFONDAVTALE-301834, Link), Oil4Feed (NFR-HAVBRUK2 302543, Link), LIGNOLIPP (NFR-BIONÆR-305215, Link), DeepHyperSpec (NFR-FRINATEK-289518, Link), Bio4Fuels (NFR-FMETEKN 257622, Link), LipoFungi (NFR-BIONÆR 268305, Link).

International collaboration:
The sensor and AI enhanced bioprocess development research and platform has attracted broad international attention. The BioSpec group has been involved in several international project initiatives in the field and we expect that we soon will have success in winning more EU funding within this area.

The BioSpec group is a member of international European consortium on fungal fermentation and bioproduction Eurofung and the European Technology Platform Photonics21 which represents the photonics community of industry and research organisations (Link: Photonics21)

Knowledge and training:
The knowledge gained has been disseminated through our international summer school which educated about 180 MSc and PhD students during 2018-2023. Around 10 master theses have been built on the knowledge gained in this research.

PhD candidates:
The research of this impact case is based on approximately 15 PhD projects in total.

Patents:
The research on fungal fermentation from the LIGNOLIPP project resulted in a potential patent application. Possibilities for patenting are under investigation in collaboration with the TTO Ard.

Applied knowledge:
The BioSpec group research impacted on a wide range of Norwegian and international food, feed, biotech, bioprocess and agriculture companies (SMEs, end-users and start-ups) willing to elevate their sustainability by integrating new bioprocesses, reducing wastes and establishing production of bio-based products. The Norwegian biorefinery Norilia has placed the establishment of fermentation processes on their 10 year strategy plan as a result of three joint collaboration projects with BioSpec. An NMBU based start-up aims at exploiting BioSpec IP for the development of a fungal fermentation process.

5. Sources to corroborate the impact

- V. Shapaval, P. J. Lahtvee, J. Blomqvist, V. Passoth, N. Bonturi, H. Einarsson, J. J. Sigurðarson, S. Skugor, M. Varland. Fat making microbes for greener and sustainable industry. Fast Track to Vision 2030. NordForsk. https://norden.diva-portal.org/smash/get/diva2:1789341/FULLTEXT03

- Brønnøysunds Avis. "Lakse-slam fra landoppdrett kan bli verdi-fullt råstoff" Ingebjørg Hestvik/Volha Shapaval. Lakse-slam fra landoppdrett kan bli verdi-fullt råstoff - banett.no

- Fremtidsmat. "Fremtidens matoljer – Kan olje fra sopp, havre, mikroalger eller marine oljer bli fremtidens matolje? Og kan vi bli selvforsynt på matolje i Norge?" Anne Marit Rødland/Volha Shapaval http://fremtidsmat.no/author/matadmin/

- Forskningsdagene. "Blir sopp fremtidens fiskefôr?" Elin Scott/Volha Shapaval https://www.forskningsdagene.no/nyheter/blir-sopp-fremtidens-fiskefor/

- Forskning.no "Én fjær kan omvandles til mat" Georg Mathisen/Vincent Eijsink/Volha Shapaval https://forskning.no/bioteknologi-fisk-mat/en-fjaer-kan-omvandles-til-mat/2095668

- Forskning.no "Bruker muggsopp til å lage sunn mat av tre og fett. Fett, tre og bryggerirester skal gi mennesker sunn mat. Nøkkelen er noe så hverdagslig som muggsopp" Georg Mathisen/Volha Shapaval. Bruker muggsopp til å lage sunn mat av tre og fett (forskning.no)

- Forskning.no "Slik vil forskere vil lage biodiesel og medisin av muggsopp og treflis" Georg Mathisen/Volha Shapaval. Slik vil forskere vil lage biodiesel og medisin av muggsopp og treflis (forskning.no)

- Forskning.no "Forskere kan skape mat og drivstoff av skogavfall" Georg Mathisen/Simona Dzurendova/Volha Shapaval. Forskere kan skape mat og drivstoff av skogavfall (forskning.no)

Automated drilling

Institution: NORCE Norwegian Research Centre
Administrative unit: Energy and Technology (EAT)
Title of case study: Automated drilling
Period when the underpinning research was undertaken: 2000 - present
Period when staff involved in the underpinning research were employed by the submitting institution: Some of the researchers have been employed from the start and all the way up to now, others have been recruited during the period.
Period when the impact occurred: 2014 - present

1. Summary of the impact (indicative maximum 100 words)

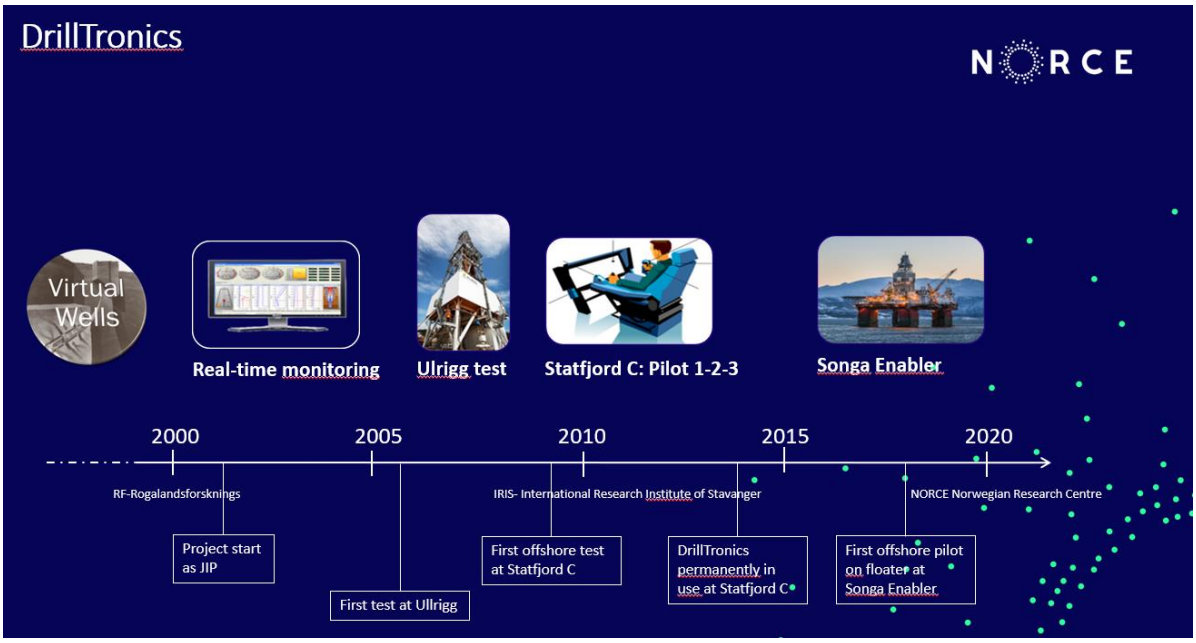

Figure 1: Timeline for the development, industrialization and commercialisation of DrillTronics

The service company Sekal was established in 2011 based on results from research and development at RF-Rogalandsforskning and IRIS. Novel products and services for drilling automation are made available to the industry. Sekal is the market leader within drilling automation and real-time drilling engineering. A total of 14 large international companies have used the technology. The technology has been used to optimize the drilling performance in more than 900 well around the world. Sekal has now 45 employees in Norway and an office in Aberdeen with 80-90 employees.

The research group Energy Modelling and Automation (previously Drilling and Well Modelling) at IRIS/NORCE have continued with independent research and development within drilling automation for knowledge building and innovation. A large part of the research has been, and still is, important for further development of the products DrillScene and DrillTronics.

The research results have been openly and widely published at conferences and in journals. The research team has also been very active in international committees to promote interoperability standards to ease the deployment of drilling automation, donated open-source software and contributed largely to increased global knowledge about drilling automation.

2. Underpinning research (indicative maximum 500 words)

Mathematical modelling and experimental investigation of subsurface aspects of the drilling process started in the late 80s at RF- Rogaland Research. Experiments were performed in laboratory setups and at the full-scale test rig Ullrigg which now is a national research infrastructure. The research and development activities resulted in software tools for planning drilling operations. These software tools are now after several steps commercially available globally through Slb and Oliasoft.

From early 2000 the R&D focus was directed towards realtime-applications for drilling process monitoring and automation. The basis for developing solutions was mathematical models for the drilling process, methods for updating uncertain parameters in drilling process models during the operation, a deep understanding of all the technical and human aspects of the drilling process, a deep understanding of measurements made in connection with the drilling process, proper software architecture and software development methods, fast and robust algorithms and data transmission, deep knowledge about automation and a high focus on safety aspects. Other complicating factors when developing solutions are that drilling is a safety critical operation and a high-cost activity with several different commercial players involved.

Some of the main milestones:

- **Transient cuttings transport**: A transient cuttings-transport model has been obtained by integrating closure laws for cuttings transport into a transient drilling model that accounts for both fluid transport and drillstring mechanics. It is then possible to get a continuously updated prognosis of the distribution of cuttings in suspension and in beds along the annulus. This information can be of prime importance for making decisions to deal with and prevent poor hole-cleaning conditions. (https://doi.org/10.2118/163492-PA)
- **Transient torque and drag model:** Eric Cayeux developed a drill-string dynamic modelling solution that runs in real-time. The model considers the whole drill-string, allowing for the extension of drilling automation functions to very dynamic conditions like those encountered on a floater. (https://doi.org/10.2118/189642-MS) This model has been mandatory for the expansion of DrillTronics business area to include floaters. First used in a drilling campaign by Equinor in the Barents Sea in 2017. More recently, Sekal, Equinor and RCN have financed the development of new methods for solving the full transient displacement of a drill-string including the lateral movement through the project 6n DOF Transient Torque&Drag. The availability of a real-time compatible vibration model should make it possible to develop methods to reduce unnecessary drill-string vibrations with the direct consequence of decreasing energy consumption during drilling operations, reducing the duration of drilling operations and possibly experiencing fewer drilling incidents.
- **SmartAutoROP:** A new sage drilling optimization functionality for increased rate of penetration within drilling constraints running in shadow mode on a Equinor rig in 2022 and 2023. The aim is to take it into use in active mode during 2024.

The early research activity was financed largely by the industry. Later, the two research centres SFI DrillWell and SFI DigiWells hosted by NORCE have been important instruments for financing and for close collaboration with the industry. NORCE's infrastructures on the National Roadmap, OpenLab Drilling and Ullrigg, have been important for testing and demonstrations. Results have frequently been published at the most important conference for the drilling industry and in journals.

Chief scientist Eric Cayeux has been the leading scientist in the research group and in 2022 he received the global Drilling Engineering Award (page 21) for his work within drilling automation.

In 2021 a new key milestone was achieved by the research team. After development of a very innovative solution, the world's first autonomous full-scale autonomous drilling operation was demonstrated at Ullrigg, (https://doi.org/10.2118/210229-MS). A total of 500 m length was drilled fully autonomously, the decisions were taken by the system itself by using the AI method Markov decision process. The development and demonstration were performed in a Joint Industry Project also supported by RCN. Video and information can be found here.

Involved researchers at NORCE:

Eric Cayeux: Chief Scientist at NORCE, Energy and Technology Division (2004-present)
Benoit Daireaux: Chief Scientist at NORCE, Energy and Technology Division (2009-present)
Erik W. Dvergsnes: Senior Scientist at NORCE, Energy and Technology Division (2004 - present)
Fionn Iversen: Chief scientist at NORCE, Energy and Technology Division (2009-present)
Helga Gjeraldstveit: Research Director at NORCE, Energy and Technology Division. (2001 - present)
Jan Einar Gravdal: Chief Scientist at NORCE, Energy and Technology Division (2002-present)
Rodica Mihai: Senior Scientist at NORCE, Energy and Technology Division (2012-present)
Adrian Ambrus: Senior Scientist at NORCE, Energy and Technology Division (2017-present)
Erlend H. Vefring: Center Director SFI DigiWells, Acting SVP Energy at NORCE, Energy and Technology Division (1991 - present)

3. References to the research (indicative maximum of six references)

Eric Cayeux, "On the Importance of Boundary Conditions for Teal-Time Transient Drill-String Mechanical Estimations", Paper presented at the IADC/SPE Drilling Conference and Exhibition, Fort Worth, Texas, USA, March 2018. Paper Number SPE-189642-MS, https://doi.org/10.2118/189642-MS

Eric Cayeux, T. Mesagan, S. Tanripada, M. Zidan, K.K. Fjelde, «Real-Time Evaluation of Hole-Cleaning Conditions With a Transient Cuttings-Transport Model", SPE Drilling and Completion, Journal, https://doi.org/10.2118/163492-PA

Eric Cayeux, Benoît Daireaux, Erik Wolden Dvergsnes, Gunnstein Sælevik, "Early Symptom Detection on the Basis of Real-Time Evaluation of Downhole Conditions: Principles and Results From Several North Sea Drilling Operations", SPE Drill & Compl 27 (04): 546–558. Journal paper 2012. Paper Number: SPE-150422-PA, https://doi.org/10.2118/150422-PA

Eric Cayeux, Erik W. Dvergsnes, F. Iversen: "Real-Time Optimization of the Drilling Process—Challenges in Industrialization", Paper presented at the SPE/IADC Drilling Conference and Exhibition, Amsterdam, The Netherlands, March 2009. Paper Number: SPE-119650-MS https://doi.org/10.2118/119650-MS

Eric Cayeux, Benoit Daireaux, Adrian Ambrus, Rodica Mihai and Liv Carlsen, "Autonomous Decision-Making While Drilling", Energies 2021, https://doi.org/10.3390/en14040969

Rodica Mihai, Eric Cayeux, Benoît Daireaux, Liv Carlsen, Adrian Ambrus, Per Simensen, Morten Welmer, Matthew Jackson, "Demonstration of Autonomous Drilling on a Full-Scale Test Rig" Paper

presented at the SPE Annual Technical Conference and Exhibition, Houston, Texas, USA, October 2022. Paper Number: SPE-210229-MS
https://doi.org/10.2118/210229-MS

4. Details of the impact (indicative maximum 750 words)

Sekal was established based on the research results from RF-Rogaland Research and IRIS through the products DrillScene and DrillTronics in 2011. With Fionn Iversen and Eric Cayeux as inventors a patent for DrillTronics was awarded in 2015, and transferred to Sekal 31.12.2018 before the exit of the company in 2019 when Sumitomo acquired Sekal. The research group at IRIS and later NORCE have continued with independent research and development within drilling automation for knowledge building and innovation. Sekal has acquired the most relevant models for further development of the products DrillScene and DrillTronics, and with support from NORCE. One of the most important achievements was when DrillTronics was enabled on floaters. In 2019 Transocean announced drilling automation of six floaters.

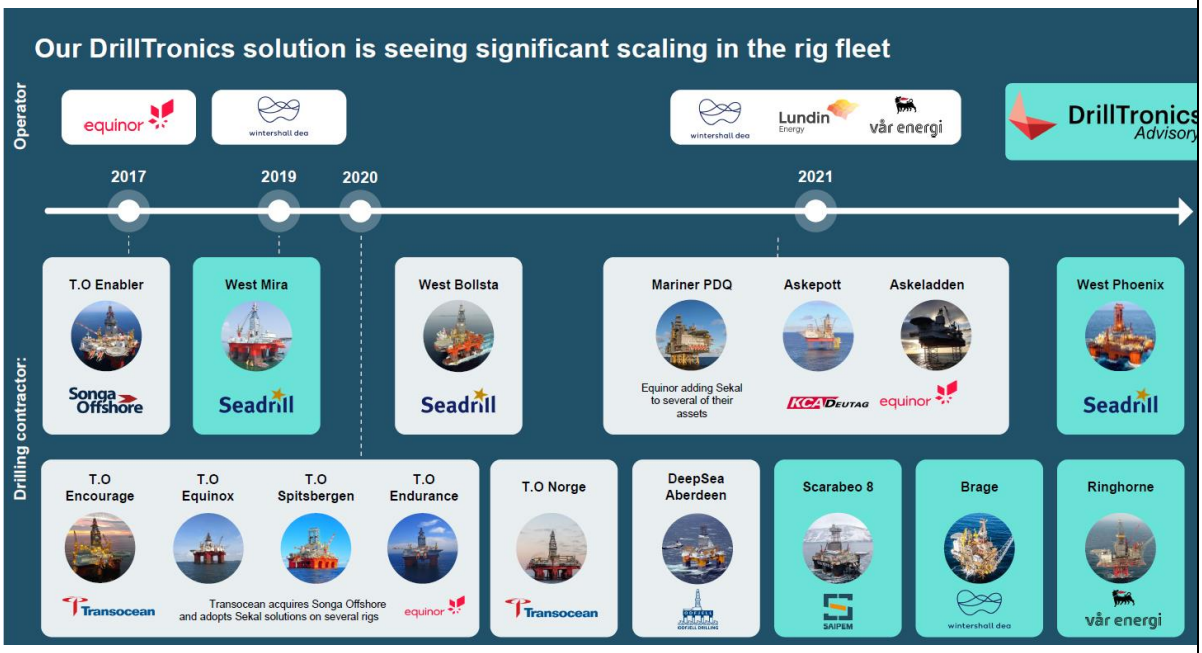

Figure 2: With the transient torque and drag model developed by NORCE, the market area was expanded to also include floaters. As floaters have high drilling activity, we can see how this increased the number of DrillTronics installations. (Courtesy of Sekal)

En bore-app sparte Statoil for 100 millioner i Barentshavet

Figure 3: In 2017 DrillTronics was used on a floater for the first time in a drilling campaign for Statoil (now Equinor) in the Barents Sea. In Norwegian newspapers you could read that Statoil had saved 100 million NOK on a drilling-app (DrillTronics). (From sysla.no)

Sekal is the market leader within drilling automation and real- time drilling engineering. A total of 14 large international companies have used the technology and the technology has been used to optimize the drilling performance in more than 900 well around the world. The products contribute to improved operational efficiency and safer operations with reduced environmental impact in terms of:

- Increased distance drilled per day
- Improved operational uptime
- Reduced drilling and completion error rate
- Improved well delivery quality
- Reduced risk of well events
- Reduced carbon footprint per well

The analysis company Rystad evaluated the effects of the RCN support of R&D activities from 2008 – 2018. They estimated that advanced drilling methods such as automated drilling has the potential to increase the production volume with 3.2 billion barrels of oil in the period between 2019 and 2050 at NCS. Rystad made another report analysing the cost and emissions reductions by using Sekal's automation technology in 2021. A full global adoption Sekal's technology has the potentials of reducing CO2 emissions by 2.9 million tons, and cost can be reduced by 17 billion per annum.

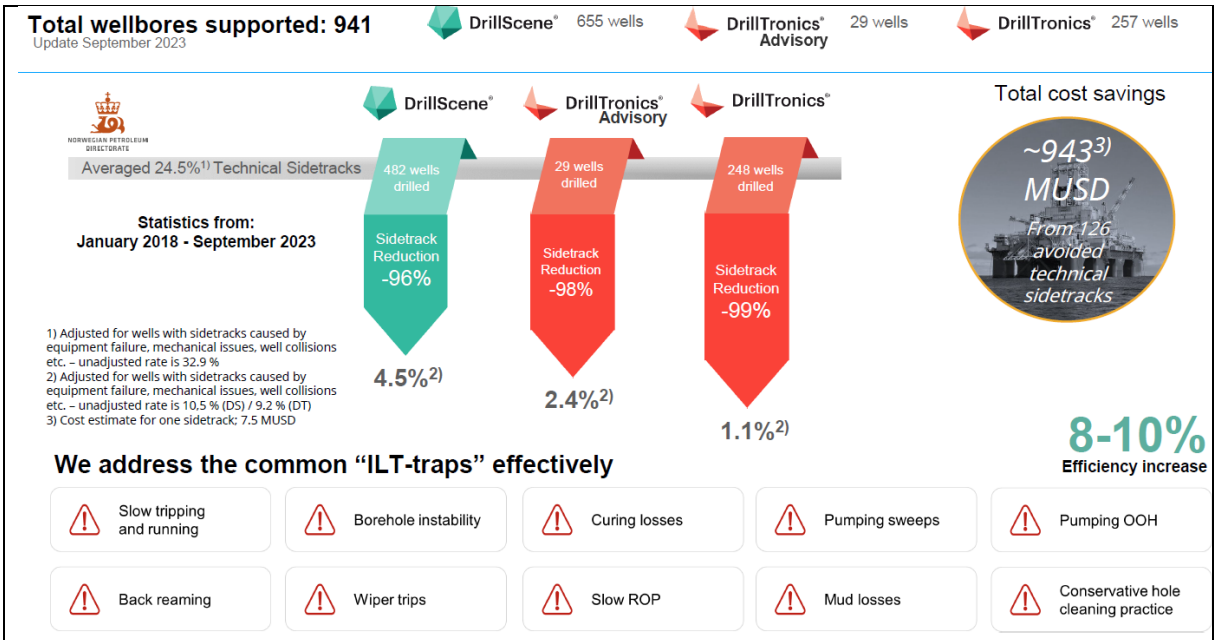

Figure 4: Overview made by Sekal on how the technology reduce the number of technical sidetracks and the related financial savings. (Courtesy of Sekal)

The research results have been openly and widely published at conferences and in journals. The research team has also been very active in international committees to promote standards for drilling automation, donated open-source software and contributed largely to increased global understanding of drilling automation.

The knowledge and technology have also been used when drilling wells for CO2 storage at NCS (Northern Light) and may play a very important role for drilling of geothermal wells.

5. Sources to corroborate the impact (indicative maximum of ten references)

- Bjørn Rudshaug, Equinor, email: bjoru@equinor.com
- Sigve Hovda, Equinor, email: sihov@equinor.com
- Mohsen Karimi Balov, Equinor, email: mokb@equinor.com
- Morten Welmer, Sekal, email: mw@sekal.com

Impact case guidelines

NORCE Norwegian Research Centre Energy & Technology 2

Institution: NORCE Norwegian Research Centre
Administrative unit: Energy and Technology
Title of case study: Technology development and commercialization
Period when the underpinning research was undertaken: 2003-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2003-2022
Period when the impact occurred:2012-2022

1. Summary of the impact (indicative maximum 100 words).

- Technology development and commercialization is a central part of the activities in the energy and technology division. The impact of these activities are new products and processes, new companies and workplaces. We develop our own IPR to facilitate research and commercialization activities, spin off companies and licensing. In the period we can mention spin off companies such as XSENS, Offshore Sensing, and Indikel. We will in this impact case focus on the impact of one of cases, XESNS, now a company providing clamp-on ultrasonic measurement technologies. Starting in basic research ending in a sound company with stable, growing work force.

- **Underpinning research** (indicative maximum 500 words)

The underpinning principles and work are based on ultrasonic guided wave technology and has its roots before the reporting period. The idea was to combine non-invasive clamp-on transducers and leaky Lamb waves to generate a wide-beam sound field in the flow. This would improve the robustness to entrained gas, particles, water, and wear in the flow, relative to traditional multipath flowmeters. The initial work was started with a Strategic Institute Program (SIP) in 2003, followed in 2007 by a competence building project, and followed up by the IPN project (RCN p. no. 235372) Multiphase flow and early fault detection (2014-2017), CMR (now NORCE) acted as the project manager on behalf of XSENS AS, invoicing all management hours to XSENS AS and reporting to XSENS CEO. In addition, the R&D work was performed by CMR in close collaboration with XSENS, and with scientific advice from XSENS's other collaboration partners. The main objective of the project was to "Develop a robust, reliable, and high-accurate non-invasive ultrasonic guided wave multiphase subsea flowmeter with bespoke diagnostics functionalities". The main findings in the project were related to a functional and optimized design for acoustic transducers emitting acoustic signals across both the centre of the pipe and along chordal paths off centre of the pipe. The signals were then picked up with similar transducers. This gave a cross-sectional overview of the flow in the pipe, allowing for high accuracy calculation of the amount of fluids flowing through the pipe. The research ranged from modelling of sound wave propagation and transducer design to development and testing of first laboratory prototypes complete with transducers (drawn and produced by Prototech AS, at the time a daughter company of CMR), and electronics developed by CMR.
In the DEMO- (RCN p.no. 272124) and FORNY20-projects (RCN p.no. 267824) that spun out from the above mentioned IPN project, NORCE provided R&D services, and a significant amount of flow loop testing in the NORCE multiphase flow loop facility, circulating a known amount of water, diesel and/or gas.

The FORNY project, "XSENS Ship fuel meter", developed methodologies to differ between various fuel qualities by investigating the velocity of sound through the fuel. Additionally, the technology was scaled to the smaller fuel pipes aboard a ship compared to the larger scale pipes focused in the earlier IPN project. The maritime industry must report consumption of various fuel qualities. The DEMO-project, "Advanced non-invasive subsea and topside flow meter", focused on further developing the technology for a demonstration in realistic environments, and XSENS implemented the technology in a demonstration installation.
Later, NORCE has contributed with contractual research and flow loop testing for XSENS, both within measurement science and within flow simulations considering both effects of flow profiles and effects of fluid properties.

- *Magne Husebø, business developer at CMR, CEO of XSENS from company establishment*
- *Remi Kippersund, main inventor and Senior scientist at CMR, VP R&D at XSENS from 2016*
- *Kjell Eivind Frøysa, background development, project manager on initial KMB, Chief Scientist and Department manager with CMR until 2015 Special adviser with NORCE (20%), main position at HVL, heavily involved in the IPN project.*
- *Per Lunde: underpinning development, project manager SIP 2003-2006 (incl. initiation of underpinning research leading to XSENS AS), supervisor PhD candidate under UiB-CMR Petromaks project (2007-2009), Senior Scientist and Department Manager CMR (1985-2008), UiB professor (2008-present), Scientific Advisor (20 %) CMR/NORCE (2008-2019), member of Xsens's Advisory Board (2013-2017*

3. References to the research (indicative maximum of six references)

Outputs from the IPN (RCN p. no. 235372): Fundament for RCN p.nos. 267824 and 272124, and M Aanes, RA Kippersund, KD Lohne, KE Frøysa, P Lunde, *Time-of-flight dependency on transducer separation distance in a reflective-path guided-wave ultrasonic flow meter at zero flow conditions,* Journal of the Acoustical Society of America, 2017, https://doi.org/10.1121/1.4996851

DEMO-project, RCN p.no. 272124: Xsens topside flow meter passed TRL 6 and subsea flow meter passed TRL4. Commercial contracts were awarded based on the test results. Xsens was awarded "Spotlight on New Technology" at OTC 2019 in Houston.

The research has resulted in that the company now holds 5 patent families on "Flow apparatus" (Norwegian Patent 331687), "Sensor apparatus and methods for measuring flow" (Norwegian Patent NO20231161A1) were developed by inventors from CMR/NORCE and XSENS, followed by assignment of ownership to XSENS. The other three patents have been filed by XSENS, with inventors from XSENS.

R. A. Kippersund, M. Husebø, P. Lunde, K.-E. Frøysa, P. Thomas, K.D. Lohne, J.O. Hellevang, "Sensor apparatus", US patent No. US 10,317,262 B2; filed Dec. 29, 2014, granted 2019.06.11:

R. A. Kippersund, M. Husebø, P. Lunde, K.-E. Frøysa, P. Thomas, K.D. Lohne, J.O. Hellevang, "Sensor apparatus and method for measuring flow", US patent No. US 10,557,731 B2; filed Dec. 29, 2014, granted 2020.02.11

Kippersund, R.A., Frøysa, K.-E. and Lunde, P., "Flow measuring apparatus", US patent No. US 8,141,434 B2; filed 2010.05.07, granted 2012.03.27

https://prosjektbanken.forskningsradet.no/en/explore/projects?Kilde=FORISS&distribution=Ar&chart=bar&calcType=funding&Sprak=no&sortBy=score&sortOrder=desc&resultCount=30&offset=0&Fritekst=xsens

4. Details of the impact (indicative maximum 750 words)

XSENS Flow Solutions provides clamp-on ultrasonic measurement technology based on an innovation that began in the early 2000s at Christian Michelsen Research (now NORCE). In 2013, CMR established XSENS AS with Magne Husebø as CEO and headquarters in Bergen, Norway, to bring this innovation to market. Today, the patented technology is in use on a global scale by large operators for high accuracy flow and fraction measurement of different types of liquids, gases and other media. The company has expanded its owner base with 3 seed-fund. Won «Offshore Technology Conference» Spotlight on new Technology - Small Business Award, Houston, USA in 2019 and «ADIPEC Oil&Gas start-up of the year», in Abu Dhabi in 2020. Their products are sold to several sites and customers, and they are expanding their portfolio. They have expanded their domain from Oil & Gas to process industry and water supply, with accompanying products and services.
The company now has 16 (31.12.22) employees and are located at modern office and production premises in Godvik close to Bergen.

The measurement technology group at NORCE have contributed to the development of the base technologies, especially in the first years of operations, particularly through IPN project (RCN p. no. 235372), FORNY project (RCN p.no. 267824) and DEMO project (RCN p.no. 272124). In addition we have conducted a significant amount of tests in our flow infrastructure, and supplied R&D services as described in section 1. The underpinning research was crucial for the development of the first laboratory prototypes, then the first industrial prototypes, and later for optimization of the technology and adaption to new applications. During the period, XSENS has hired R&D personnel, and the R&D work that in the early days was performed solely by NORCE (CMR), was taken over by XSENS, first by the formal responsibility in the IPN, and then gradually also with the day to day R&D efforts in later projects. Over time, XSENS has increased its work force and the R&D activities in XSENS has gradually changed focus over to product robustness and improved production methods. This development has reduced the need for R&D competence offered by NORCE. Although XSENS now is to be considered as any other client (even if NORCE still owns 48 %) and further develop their products with internal R&D resources, the full XSENS product portfolio has originated from R&D performed by NORCE (and CMR).

5. Sources to corroborate the impact (indicative maximum of ten references)

- Johan Christopher Giertsen, former VP of Business development at CMR, then EVP Commercialisation at NORCE from 2018, Chairman of the Board of XSENS from company establishment (representing NORCE Innovation AS, the largest investor and largest owner in XSENS)
- Ingvar Katmo, Partner in Proventure Seed II AS (investor in Xsens). Board member in XSENS from 2016.
- Jon Trygve Berg, Partner in Sarsia Fonrd II AS (investor in XSENS). Board member in XSENS from 2016.
- John-Arne Hørløck, Investment Director, Investinor (investor in XSENS). Board member in XSENS since 2019.

NORCE Energy and Technology 3

Institution: NORCE
Administrative unit: Energy and Technology
Title of case study: Visualization and analytics software
Period when the underpinning research was undertaken: 2006 - 2023
Period when staff involved in the underpinning research were employed by the submitting institution: 2007-2023
Period when the impact occurred: 2007-2023

1. Summary of the impact (indicative maximum 100 words)

An integral part of the work in several of the research groups are development of research based visualization and analysis software solutions that make significant impact in their application areas. Exemplified here by three different solutions in different domains.
Enlighten is a general interactive visualization framework developed as an extension of the doctoral work of one of our employees.
NLive is a visualization solution that enables high-performance visualization of georeferenced and time-stamped datasets in 3D on a virtual globe, on the web or in virtual reality.
LSSS (Large scale survey system) is a solution for supporting abundance estimation of fish schools interpreting large scale acoustic data.

2. Underpinning research (indicative maximum 500 words)

Development of NLive began in 2011. NLive started out as a small system for visualizing maps, terrain and realtime drone flights in 3D with a focus on high performance. This focus has been a guiding principle for the further research and development of the system. The current version of NLive builds on more than ten years of research into systems, algorithms and tools for scalable processing, storing, serving and rendering of timestamped and/or georeferenced datasets, with different versions of NLive tailored to different application areas.

LSSS is a software system for scrutinizing marine acoustic data from echosounders and sonars. The software is developed in cooperation with the Norwegian Institute of Marine Research (IMR). The development started in 2002 and the system was implemented in operational use at IMR in 2007. LSSS has since been continuously maintained and improved. The solution is also used by customers in a number of other countries. The main workflow in LSSS is to assign species categories to areas of the acoustic data. This is done interactively using the echogram which shows the main echosounder data, and auxiliary data views such as map, trawl samples, and frequency responses. The LSSS system also contains an automatic preprocessor for performing data improvements, such as noise removal, and various automatic analyses, such as bottom detection, school detection and species classification.

Enlighten was originally developed by Ove Daae Lampe during his PhD (2011) on Interactive Visual Analysis (IVA) of Process Data. The application provided powerful functionalities for IVA that has later been rewritten with web portal functionality, enabling access to IVA functionalities through web portals. The user can use brushing and linking to explore complex data sets to discover correlations and interesting properties hidden in the data. Brushing refers to selecting a subset of the data using the mouse. Linking involves two or more plots showing different attributes from the same data sets. If the updates in the linked plots are close to real-time while brushing, the user can perceive complex trends in the data by seeing how the selections in the linked plots vary depending on changes in the brushed subset. This interactivity, especially for large data sets, requires GPU acceleration of the graphics rendering.

Ove Daae Lampe, Senior researcher Digital Systems – Enlighten
Tor Langeland, Senior researcher Digital Systems - Enlighten
Daniel Stødle, Senior Researcher DARWIN - NLive
Inge Eliassen, Senior Researcher Digital Systems - LSSS

3. References to the research (indicative maximum of six references)

Authors: John F Dehls; Yngvar Larsen; Petar Marinkovic; Tom Rune Lauknes; Daniel Stødle; Dag Anders Moldestad
Title: INSAR.No: A National Insar Deformation Mapping/Monitoring Service In Norway -- From Concept To Operations
Year: 2019
Type of output: IEEE International Geoscience and Remote Sensing Symposium proceedings
ISSN 2153-6996
https://doi.org/10.1109/IGARSS.2019.8898614

Authors: Michalek, Jan ; Atakan, Kuvvet ; Rønnevik, Christian ; Langeland, Tor ; Daae Lampe, Ove ; Fonnes, Gro ; Mykkeltveit, Svein ; Magnus Christensen, Jon ; Baadshaug, Ulf ; Kierulf, Halfdan Pascal ; Grøtan, Bjørn-Ove ; Olesen, Odleiv
Title: EPOS-Norway - Integration of Norwegian geoscientific data into a common e-infrastucture.
Year: 2020
Type of output: EGU General Assembly 2020, EGU2020-18842
DOI:10.5194/egusphere-egu2020-18842

Author(s) Tor Langeland; Jeremy Cook; Sigurd Tjøstheim; Trond Kristiansen; Gro Fonnes; Ove Daae Lampe; Geir Pedersen; Lionel Camus
Title: A Data Management Platform for Data Harvesting and Analysis from Autonomous Marine Measurement Platforms
Year of publication: 2019
Type of output: OCEANS 2019 - Marseille, Marseille, France, 2019, pp. 1-5, https://doi.org/10.1109/OCEANSE.2019.8867275.

Authors: Korneliussen, R. J., Heggelund, Y., Eliassen, I. K., and Johansen, G. O.
Title: Acoustic species identification of schooling fish.
Year of publication: 2009.
Type of output: ICES Journal of Marine Science, 66: 1111–1118

Authors: Rolf J. Korneliussen; Yngve Heggelund; Gavin J. Macaulay; Daniel Patel; Espen Johnsen; Inge K. Eliassen
Title: Acoustic identification of marine species using a feature library
Year: 2016
Type of output: Article in Methods in Oceanography
https://doi.org/10.1016/j.mio.2016.09.002

4. Details of the impact (indicative maximum 750 words)

NLive is the foundation for several of NORCE's applications of 3D visualization on the web. It provides the frontend for the InSAR Norway ground motion service (https://insar.ngu.no), and comparable services outside Norway, such as InSAR Sweden and the European Ground Motion Service, enabling users to visualize ground deformation datasets that in total are approximately 100 TB. NLive is also being used as the 3D visualization component of the European Space Agency's Cryosphere Virtual Laboratory (https://cvl.eo.esa.int/), serving as a visualization playground for interactive research and development of new algorithms for processing remote sensing datasets. NLive has been used extensively for NORCE's drone activities for monitoring and sharing of flight data both internally and externally.

For Enlighten-web, impact has so far been mainly as a tool in research. The EPOS-N portal (https://epos-no.uib.no/eposn-data-portal/) is implemented based on Enlighten. Enlighten is also adopted as a core service in the EPOS -ERIC infrastructure. It is used in SFI Smart Ocean as visualization and analytics portal for data in the SFI Smart Ocean and as visualization portal for the data gathered in the One Ocean Expedition. Enlighten-web was also used for realizing a data management platform for harvesting data from autonomous marine measurement platforms. In this project unmanned underwater and surface vessels were used for gathering sensor data. Enlighten formed a central part of the data management platform.

LSSS was developed in close collaboration with the Institute of Marine Research and is deployed by several marine research institutes around the world. It is used in abundance estimation of different categories of fish species and thus plays an important role in determining fishing quotas and numbers for the ICES stock assessment for species in Norwegian coastal waters. It is an invaluable tool for researchers at the Norwegian Institute of Marine Research and is also used in course works and education. The software has also been adapted to work on sea drones.

5. Sources to corroborate the impact (indicative maximum of ten references)

LSSS:

Rolf Korneliussen, Head of Research, Okosystem acoustics
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John F. Dehls
Scientist, Geological Survey of Norway
E-mail: john.dehls@ngu.no
Phone: (+47) 73904454

[NORCE E&T] [5]

Institution: NORCE Norwegian Research Centre
Administrative unit: Energy and Technology
Title of case study: Synthetic Aperture Radar Interferometry (InSAR) for ground deformation
Period when the underpinning research was undertaken: 2005-now
Period when staff involved in the underpinning research were employed by the submitting institution: 2005-now
Period when the impact occurred: 2017-now

1. Summary of the impact

Automated SAR Interferometry (InSAR) based on the Sentinel-1 satellites combined with the NLIVE visualization tool has been used to set up operational Ground Motion Services (GMS) in Norway (www.insar.ngu.no), Sweden (https://insar.rymdstyrelsen.se/), and Europe (https://egms.land.copernicus.eu/). The services led to the discovery of unknown landslides that can endanger population and infrastructure. Mapping and monitoring these hazardous landforms contribute to assessing the needs for further actions to mitigate the risk in mountainous regions. InSAR also documents urban subsidence and deformation of man-made structures that can lead to destabilization or long-term damage. At NORCE, InSAR technology led to advanced research in geosciences to document the dynamics of periglacial landforms especially sensitive to changing climate.

2. Underpinning research

Norway was the first country in the world that delivered fully open and free InSAR-based ground deformation data at the national scale, through an interactive web visualisation system. The technologies to process the satellite data over the entire country and visualize the data in a 3D portal have been developed by researchers from the NORCE Energy and Technology Division (formerly Norut Northern Research Institute). The development of the InSAR chain started 20 years ago, but the launch of Sentinel-1 (2014) enhanced the InSAR ability to large-scale InSAR mapping. The first project funding research towards an operational nationwide Ground Motion Service started in 2016. The InSAR Norway Ground Motion Service (GMS) was released in November 2018 and annual updates have been delivered since then. A new phase of the InSAR Norway project has started in 2023 and include maintenance of the software system , as well as development subprojects to develop new products and services (e.g. development of a GMS in Svalbard). Building on the international recognition of the world-leading expertise of NORCE in large-scale InSAR processing, several follow-up public services were funded in the past years (InSAR Sweden: 2021-2022 ; the European Ground Motion Service: 2021 and onwards, first release in 2022). Since their release, the GMS are used operationally by a wide range of users, from public administrations and private companies.

In parallel to this technical development, The InSAR processing developed at NORCE contributed to advanced geoscientific research to advance our understanding on ground dynamics in Arctic and mountainous regions. Most InSAR-related applied research performed at NORCE between 2015 and 2022 is focusing on permafrost and landslide dynamics, with a focus on the Norwegian Arctic and Subarctic territories. The specific research objectives were to further document and interpret the spatio-temporal displacement patterns of hazardous rockslides and the seasonal and decadal changes of ground surface dynamics related to freeze/thaw processes, in relation with climate change. In the past 10 years, two PhDs funded by NORCE focused on InSAR applied to geosciences (projects granted by funded Troms County Council, project number 217720 and grant number RDA12/165 and by the Space Programme of the Research Council of Norway, project number 263005). The PhDs were fulfilled in 2017 and 2021 and contributed to well-cited

publications in this field (see Sections 3 and 5). As a continuation of this work, several projects are now ongoing to further exploit InSAR-based products for operational assessment of changing permafrost conditions (infrastructure and geohazard management) and for climate change research (coupling with modelling, generation of new parameters of the Essential Climate Variable ECV Permafrost).

Key Researchers

- Yngvar Larsen, senior researcher (2007-now). Research on InSAR algorithms and processing chain development for large-scale ground motion services.
- Daniel Stødle, senior researcher (2012-now). Research on 3D interactive web visualization tools using for large-scale ground motion services.
- Tom Rune Lauknes, senior researcher (2012-now). Research on InSAR algorithm and processing chain development for geoscientific purposes and infrastructure management.
- Line Rouyet, researcher (2013-2023), PhD candidate (2017-2021), senior researcher since 2023. Research on InSAR exploiting for permafrost science, landslides and geohazard assessment.
- Harald Øverli Eriksen, PhD candidate (2013-2017). Research on InSAR exploiting for landslides and geohazard assessment.

3. References to the research

Major deliveries of free data on openly available Ground Motion Services:

- InSAR Norway Ground Motion Service (www.insar.ngu.no). Details on consortium and NORCE contribution: www.insar.no. First open delivery in November 2018.
- InSAR Sweden Ground Motion Service (https://insar.rymdstyrelsen.se/). The service is powered by the InSAR Norway project team.
- European Ground Motion Service (https://egms.land.copernicus.eu/). Details on the service and available products: https://land.copernicus.eu/en/products/european-ground-motion-service

Scientific publications as part of the two PhD thesis funded by projects led by NORCE (formerly Norut):

- Harald Ø. Eriksen. PhD thesis defended and accepted in 2017 “Combining Satellite and Terrestrial Interferometric Radar Data to Investigate Surface Displacement in the Storfjord and Kåfjord Area, Northern Norway” https://munin.uit.no/handle/10037/11679. The work was funded by the Troms County Council, project number 217720 and grant number RDA12/165 (PI: Tom Rune Lauknes, NORCE).
- Line Rouyet. PhD thesis defended and accepted in 2021 “Ground Dynamics in the Norwegian Periglacial Environment Investigated by Synthetic Aperture Radar Interferometry” https://munin.uit.no/handle/10037/22231. The work was funded by the Space Programme of the Research Council of Norway, project number 263005. (PI: Tom Rune Lauknes, NORCE).

4. Details of the impact

InSAR large-scale processing and release though the Ground Motion Services:

- Dissemination: open release of datasets through Ground Motion Services hosted by public institutions (see links in Section 5). First GMS launch (InSAR Norway): November 2018.
- Contribution from other key research partners: PPO.Labs (R&D partnership), NGU (public institution in charge of the service and main user), NVE (main user).
- EGMS is operated by a large European consortium, including e-geos (IT), TRE Altamira (FR) and GAF (DE) as and NORCE as core partners. NORCE is responsible for the processing of

the Nordic and the Baltic countries and Poland, as well as operation of the visualisation and data access tool EGMS Explorer.

InSAR applied to geoscience (landslide research and permafrost science):

- Two PhD projects at NORCE (formerly Norut) led to doctoral thesis at UiT the Arctic University of Norway: https://munin.uit.no/handle/10037/11679u (submitted in April 2017, defended in October 2017) and https://munin.uit.no/handle/10037/22231 (submitted in May 2021, defended in September 2021). The main articles related to this research have been published between 2017 and 2021.
- Contribution from other key research institutions: NGU and NVE have been our main partners from the public sector (exploitation of results for geohazard management). UiT, UNIS and UiO have been our main academic partners within geohazard and permafrost research.

5. Sources to corroborate the impact (indicative maximum of ten references)

Major deliveries of free data on openly available Ground Motion Services (GMS):

- InSAR Norway Ground Motion Service (www.insar.ngu.no). Details on consortium and NORCE contribution: www.insar.no. First open delivery in 2018.
- InSAR Sweden Ground Motion Service (https://insar.rymdstyrelsen.se/). The service is powered by the InSAR Norway project team.
- European Ground Motion Service (https://egms.land.copernicus.eu/). Details on the service and available products: https://land.copernicus.eu/en/products/european-ground-motion-service

Other relevant reports/articles related to the InSAR GMS:

- Dehls, J. F., Larsen, Y., Marinkovic, P., Lauknes, T. R., Stødle, D., & Moldestad, D. A. (2019, July). INSAR.No: A national InSAR deformation mapping/monitoring service in Norway--From concept to operations. In *IGARSS 2019-2019 IEEE International Geoscience and Remote Sensing Symposium* (pp. 5461-5464). https://doi.org/10.1109/IGARSS.2019.8898614.
- Larsen, Y. 2020. European Ground Motion Service: Service Implementation Plan and Product Specification Document. Copernicus Land Monitoring Service. European Environment Agency. https://land.copernicus.eu/en/products/european-ground-motion-service/d2_d3_combined_sip_psd-1_01_final-1.pdf/@@download/file.
- Costantini, M., Minati, F., Trillo, F., Ferretti, A., Novali, F., Passera, E., Dehls, J., Larsen, Y., Marinkovic, P. et al. (2021). European ground motion service (EGMS). In *2021 IEEE International Geoscience and Remote Sensing Symposium IGARSS* (pp. 3293-3296). https://doi.org/10.1109/IGARSS47720.2021.9553562.

Peer-reviewed articles on InSAR applied to geoscience:

- Eriksen, H. Ø., Lauknes, T. R., Larsen, Y., Corner, G. D., Bergh, S. G., Dehls, J., & Kierulf, H. P. (2017). Visualizing and interpreting surface displacement patterns on unstable slopes using multi-geometry satellite SAR interferometry (2D InSAR). *Remote Sensing of Environment*, *191*, 297-312. https://doi.org/10.1016/j.rse.2016.12.024.
- Eriksen, H. Ø., Bergh, S. G., Larsen, Y., Skrede, I., Kristensen, L., Lauknes, T. R., Blikra, L. H. & Kierulf, H. P. (2017). Relating 3D surface displacement from satellite-and ground-based InSAR to structures and geomorphology of the Jettan rockslide, northern Norway. *Norwegian Journal of Geology, 97*(4). http://dx.doi.org/10.17850/njg97-4-03
- Eriksen, H. Ø., Rouyet, L., Lauknes, T. R., Berthling, I., Isaksen, K., Hindberg, H., Larsen, Y. & Corner, G. D. (2018). Recent acceleration of a rock glacier complex, Adjet, Norway, documented by 62 years of remote sensing observations. *Geophysical Research Letters*,

45(16), 8314-8323. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2018GL077605.

- Rouyet, L., Lauknes, T. R., Christiansen, H. H., Strand, S. M., & Larsen, Y. (2019). Seasonal dynamics of a permafrost landscape, Adventdalen, Svalbard, investigated by InSAR. *Remote Sensing of Environment*, *231*, 111236. https://doi.org/10.1016/j.rse.2019.111236
- Rouyet, L., Liu, L., Strand, S. M., Christiansen, H. H., Lauknes, T. R., & Larsen, Y. (2021). Seasonal InSAR displacements documenting the active layer freeze and thaw progression in central-western Spitsbergen, Svalbard. *Remote Sensing*, *13*(15), 2977. https://doi.org/10.3390/rs13152977.
- Rouyet, L., Lilleøren, K. S., Böhme, M., Vick, L. M., Delaloye, R., Etzelmüller, B., Lauknes, T. R., Larsen, Y. & Blikra, L. H. (2021). Regional morpho-kinematic inventory of slope movements in northern Norway. *Frontiers in Earth Science*, *9*, 681088. https://doi.org/10.3389/feart.2021.681088.
- Rouyet, L., Karjalainen, O., Niittynen, P., Aalto, J., Luoto, M., Lauknes, T. R., Larsen, Y. & Hjort, J. (2021). Environmental Controls of InSAR-Based Periglacial Ground Dynamics in a Sub-Arctic Landscape. *Journal of Geophysical Research: Earth Surface*, *126*(7), e2021JF006175. https://doi.org/10.1029/2021JF006175.

NR impact case number 1

Institution: Norsk Regnesentral
Administrative unit: Norsk Regnesentral
Title of case study: COVID-19 modelling
Period when the underpinning research was undertaken: 2017-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2019-2022
Period when the impact occurred: 2020-2022

1. Summary of the impact (indicative maximum 100 words)

During the COVID-19 pandemic in Norway, Norsk Regnesentral (NR) contributed with essential real-time research for policy planning and guidance. Already in February 2020, the COVID-19 modelling task force of the Norwegian Institute of Public Health (NIPH), of which NR was a collaborator, started developing mathematical and statistical models for scenario simulations, situational awareness, and forecasting. The aims of the mathematical modelling were manifold. We provided estimates of the reproduction number in Norway over time, both nationally and regionally. We provided predictions of hospitalisations for planning purposes and situational awareness, and provided different scenarios (vaccine strategies, intervention policies etc.). The model output and reports were used by NIPH, the Norwegian directory of health, hospitals, local and national authorities. The modelling team produced more than 200 reports during the pandemic. Our model output was also used by Holden-utvalget in the health economic evaluation of COVID-19 interventions. Moreover, NR also contributed with communication to the media during the pandemic.

2. Underpinning research (indicative maximum 500 words)

The fact that we were able to produce predictions and estimates of reproduction numbers so early in the pandemic is largely due to building on models and collaborations that were already in place before the pandemic. In the SFI BigInsight – centre for research-based innovation, of which NR is the host institute and the NIPH a partner, there had been projects focusing on epidemiological modelling. One of these was the PhD project of Solveig Engebretsen, who has been employed at NR since the end of her PhD (August 2019). This PhD project was a collaboration between the University of Oslo, NIPH, and Telenor (one of the world's largest mobile telecommunications companies). One of the subprojects of this PhD project dealt with using mobile phone data to develop a spatial model for spread of influenza in Bangladesh. The Norwegian Institute of Public Health's COVID-19 modelling task force built on this collaboration, and hence was a collaboration between NIPH, NR, the University of Oslo and Telenor. The infectious disease model which was used for situational awareness and forecasting during COVID-19 in Norway was an extension of this model to Norway and to fit COVID-19 epidemiology. The model was also based on an R-package which was developed during this PhD project.

The model is a stochastic metapopulation model and is an extension of the classical "state-of-the-art" SIR-model for infectious disease modelling. Combined with real-time data on mobility, data on hospitalisations and laboratory tests for COVID-19, the model framework was used to produce estimates of reproduction numbers, predictions of hospital beds for the different hospitals, and different scenario outputs. Throughout the pandemic, we performed real-time research, constantly developing and improving the models and framework, while at the same time producing outputs for policy planning and responding to different requests. Due to the immense computational resources necessary for timely high-dimensional stochastic inference, we also collaborated with Sigma2, who provided both computational resources in form of

reserved computing nodes on the supercomputer clusters Saga and Fram, and support. Key outputs from this research from NR were as follows:

a. We extended the model for influenza spread in Bangladesh to spread of COVID-19 in Norway, using real-time six-hourly mobility matrices from Telenor (early 2020).
b. We developed methods for estimating regional and national reproduction numbers of the model, informed by daily hospital data and daily number of positively (and negatively) tested for COVID-19. Inference in complex, stochastic metapopulation models is very difficult and computationally demanding. There was a huge time pressure for these estimates, as the data would be available Monday morning, and the estimates had to be ready for the weekly reports which were published noon of Wednesday. We thus needed to develop inference methods which could handle the high-dimensional parameter estimation (due to requiring regional reproduction numbers that changed over time). The method is called split-Sequential Monte Carlo Approximate Bayesian Computation (split-SMC-ABC) and was successful in providing timely parameter estimates during the pandemic (2020-2022).
c. For most purposes, we assumed a piecewise constant reproduction number per county in Norway. However, it is also interesting to estimate and monitor reproduction numbers which are allowed to change daily. We developed a new model for the reproduction number along with an estimation method, which was used to estimate the reproduction number in real-time. These estimates were published accompanying the piecewise constant reproduction numbers providing additional evidence. The model was fitted using a sequential Monte Carlo approach which was also very efficient and could be used in real-time. (2020-2022)
d. We provided frequent, regular publicly available situational awareness reports with estimated reproduction numbers and short-term forecasts. (2020-2022)
e. Throughout the COVID-19 pandemic, we produced multiple reports as output to specific inquiries from for example NIPH, Holden-utvalget, the Norwegian directorate of public health and the government, often involving scenarios regarding different intervention policies. One example is the age and regional prioritisation of vaccines. (2020-2022)
f. We contributed to estimating the increased transmissibility of the alpha variant based on contact tracing data from Oslo municipality. (2021)

After the pandemic, we continue contributing with research and publishing our work during the pandemic. This is both to share and document our work, but also to contribute to knowledge which can be used in future pandemics. For example, we have analysed detailed Norwegian mobility data from Telenor, finding that there is little to gain from mandatory interventions compared to recommendations in terms of social interactions (measured by mobility), (2021-2022).

The contributions to this research from NR were made by:
Solveig Engebretsen (senior researcher at NR)
Magne Aldrin (research leader at NR)
Geir Storvik (Professor II at NR and professor at University of Oslo)
Arnoldo Frigessi (Professor II at NR and professor at University of Oslo)

3. References to the research (indicative maximum of six references)

Though a lot of the work and impact in this project happened during 2020-2022, the most of the documentation in scientific journals was not published before 2023, as the pandemic was characterised by real-time research and limited capacity and time for publishing papers.

Engebretsen, S., Engø-Monsen, K., Aleem, M. A., Gurley, E. S., Frigessi, A., & De Blasio, B. F. (2020). Time-aggregated mobile phone mobility data are sufficient for modelling influenza spread: the case of Bangladesh. Journal of the Royal Society Interface, 17(167), 20190809. https://doi.org/10.1098/rsif.2019.0809

Engebretsen, S., Diz-Lois Palomares, A., Rø, G., Kristoffersen, A. B., Lindstrøm, J. C., Engø-Monsen, K., ... & De Blasio, B. F. (2023). A real-time regional model for COVID-19: Probabilistic situational awareness and forecasting. PLOS Computational Biology, 19(1), e1010860. https://doi.org/10.1371/journal.pcbi.1010860

Lindstrøm, J. C., **Engebretsen, S**., Kristoffersen, A. B., Rø, G. Ø. I., Palomares, A. D. L., Engø-Monsen, K., ... & de Blasio, B. F. (2022). Increased transmissibility of the alpha SARS-CoV-2 variant: evidence from contact tracing data in Oslo, January to February 2021. *Infectious Diseases*, *54*(1), 72-77. https://doi.org/10.1080/23744235.2021.1977382

Storvik, G., Diz-Lois Palomares, A., **Engebretsen, S.**, Rø, G. Ø. I., Engø-Monsen, K., Kristoffersen, A. B., ... & Frigessi, A. (2023). A sequential Monte Carlo approach to estimate a time-varying reproduction number in infectious disease models: the Covid-19 case. *Journal of the Royal Statistical Society Series A: Statistics in Society*, *186*(4), 616-632. https://doi.org/10.1093/jrsssa/qnad043

Kamineni, M., Engø-Monsen, K., Midtbø, J. E., Forland, F., de Blasio, B. F., Frigessi, A., & **Engebretsen, S.** (2023). Effects of non-compulsory and mandatory COVID-19 interventions on travel distance and time away from home, Norway, 2021. *Eurosurveillance*, *28*(17), 2200382. https:// doi.org/10.2807/1560-7917.ES.2023.28.17.2200382

Engebretsen, S., Rø, G., & De Blasio, B. F. (2022). A compelling demonstration of why traditional statistical regression models cannot be used to identify risk factors from case data on infectious diseases: a simulation study. *BMC Medical Research Methodology*, *22*(1), 146. https://doi.org/10.1186/s12874-022-01565-1

Chan, L. Y. H., Rø, G., Midtbø, J. E., Di Ruscio, F., Watle, S. S. V., Juvet, L. K., ... & de Blasio, B. F. (2023). Modeling geographic vaccination strategies for COVID-19 in Norway. medRxiv, 2023-08. Provisionally accepted for publication in *PLOS Computational Biology*. https://doi.org/10.1101/2023.08.16.23294112

4. Details of the impact (indicative maximum 750 words)

The COVID-19 modelling task force had impact throughout the pandemic years. There are also still ongoing efforts of documenting and disseminating the work that was done during the pandemic, and to prepare and gather knowledge for future pandemics.

Mathematical modelling constitutes a systematic framework to gather and evaluate the consequences of information from both data and knowledge, from studies and/or domain experts. Hence, output from mathematical models provides evidence which can be used to guide policies and decisions. This is particularly true in settings with limited experience and information, like for emerging pandemics of novel viruses.

During the COVID-19 pandemic, mathematical modelling has had great impact on preparedness planning and decision-making in several countries, including Norway. In Norway, evidence on effects of different interventions and short-term predictions of the number of hospital beds expected to be occupied have been used to inform policy makers at the governmental level. NR played a key role in the Norwegian Institute of Public Health's COVID-19 modelling task force. For

example, the estimates of the reproduction numbers were decisive for how much and how quickly we could lift the social contact interventions, and were frequently cited in the Norwegian media, for example by the minister of health and prime minister in the national press conferences. The R-number became a quantity of public interest and common knowledge and was regularly used in the public discourse. Something which was very special was the timeliness of our estimates and prediction, that is, how quickly we were able to put together a functioning mathematical modelling framework. This was because we could build on the already established collaborations through BigInsight between NIPH, NR, University of Oslo and Telenor.

The modelling team published more than 200 reports during the pandemic years. Many of these were frequent situational awareness reports, which were published with different frequency during the pandemic. These reports mainly contained recent estimates of the reproduction numbers and short-term forecasts. The real-time research and work during the pandemic required great efforts from all researchers involved in the modelling team, and was characterised by time-pressure, short deadlines and stress. The modelling team was producing frequent, regular reports, while at the same time improving and extending the model. Due to the computational demands, there was also little room for error, as the reports had to be ready before Wednesday at noon, and the data arrived Monday morning. There were many dynamic factors which changed during the pandemic, and we were constantly surveilling the model output and include changes where needed, for example hospitalisation probabilities and length of stays in hospital, viral properties (e.g. different variants of concern having different properties), behaviour, interventions, testing criteria, testing capacity etc.

In addition, we worked in parallel on various other specific requests, like producing output from different scenarios and intervention strategies. One example is a report evaluating different regional prioritisation strategies for vaccination. In Norway, it was chosen to distribute vaccine doses heterogeneously between regions, partly based on evidence from our modelling reports.

We also had several meetings with different hospitals explaining the model output and discussing the assumptions and whether these should be changed. We provided input to the health economic evaluation of interventions by Holden-utvalget.

The evaluation report from Koronautvalget also clearly states that the mathematical modelling had an important impact during the COVID-19 pandemic. The report states that the modelling results were directly relevant for political decisions, and that “Mathematical models of infectious diseases played a key role in the advice from the Norwegian Institute of Public Health to the Department of health (HOD) and the government, and in communicating to the general public” (translated to English from the report). The report concludes that predictions from mathematical models should also be used for policy making in future crises. They do, however, highlight the importance and difficulty of communicating uncertainty and assumptions.

NR also had an impact by communicating to the general public about infectious disease modelling and COVID-19. During the pandemic, there was a general public interest in output from mathematical modelling and theoretical quantities like the reproduction number. We also contributed to discussing and communicating about uncertainty in general.

5. Sources to corroborate the impact (indicative maximum of ten references)

Samfunnsøkonomiske vurderinger av smitteverntiltak (covid-19). Holdenutvalget. Available at: https://www.helsedirektoratet.no/rapporter/samfunnsokonomisk-vurdering-av-smitteverntiltak-covid-19

List of all modelling reports by the Norwegian Institute of Public Health's COVID-19 modelling task force: https://www.fhi.no/en/id/corona/coronavirus/coronavirus-modelling-at-the-niph-fhi/

Evaluering av pandemihåndteringen. Rapport fra Koronautvalget. NOU Norges offentlige utredninger 2023:16. https://kudos.dfo.no/documents/33400/files/29758.pdf

The Norwegian government's press conference April 6th, 2020, referring to model output and reproduction numbers, can be accessed at https://tv.nrk.no/serie/nyheter/202004/NNFA41014720/avspiller

Camilla Stoltenberg, director of NIPH, thanks BigInsight for the contributions during the pandemic (see first video): https://www.biginsight.no/news/2023/11/21/biginsight-celebration-day-was-fun

Media and public communication
Aftenposten bommer om prognoser. Igjen og igjen. Stoltenberg, C., Aavitsland, P., Rø, G., de Blasio, B. F., Frigessi, A., **Engebretsen, S**. Aftenposten 2021.
https://www.aftenposten.no/meninger/kronikk/i/7KbAKo/aftenposten-bommer-om-prognoser-igjen-og-igjen

COVID-19: The Norwegian model. Jære, L. The UNESCO Courier, Volume 2023, Issue 1, May 2023, p. 12 – 13. DOI: https://doi.org/10.18356/22202293-2023-1-4. URL: https://courier.unesco.org/en/articles/covid-19-norwegian-model

Modellering av R-tallet i sanntid. Når PhD-arbeidet plutselig blir beslutningsgrunnlag under en pandemi. **Engebretsen, S**. Dataanalyser som redder verden – science not fiction. Senter for digitalt liv Norge. Kulturhuset. November 10, 2021. Available from: https://www.youtube.com/watch?v=htJAfctRQ-w

Panel debate: HVA KAN VI LÆRE AV RUNDEN MED COVID: HVORDAN HÅNDTERER VI USIKKERHET OG ÅPENHET? Stoltenberg, C., Frigessi, A., **Engebretsen, S.,** Sandberg, H., Johansen, P.A., **Gjuvsland, E. R.** Arendalsuka August 17, 2021.

Spatial modelling of COVID-19 in Norway. **Engebretsen, S.** Impact Breakfast - Covid-19 special edition. University of Oslo. January 27, 2021.

Smittetallet R: Slik regner Folkehelseinstituttet ut hvordan korona-viruset sprer seg. Borgan, E. Forskning.no. May 25, 2020. Available from: https://www.forskning.no/epidemier-informatikk-naturvitenskap/smittetallet-r-slik-regner-folkehelseinstituttet-ut-hvordan-koronaviruset-sprer-seg/1687548

Interview NRK. **Engebretsen, S.** and Engø-Monsen, K. November 16, 2020. Available from: https://tv.nrk.no/serie/nyheter/202011/NNFA17111620/avspiller (10:39 minutes in).

Engebretsen, S., & Osnes, A. N. (2020). Matematiske modeller under en pandemi. Tidsskrift for Den norske legeforening. https://tidsskriftet.no/2020/11/kronikk/matematiske-modeller-under-en-pandemi

Abels tårn. **Engebretsen, S**., Raklev, A., Gravensteen, I.K, Jemterud, Torkil. September 3, 2021. https://radio.nrk.no/podkast/abels_taarn/sesong/202109/l_9e74951d-fd6b-4764-b495-1dfd6bf76473.

Norsk Regnesentral (NR), impact case number 2

Institution: Norsk Regnesentral (NR)
Administrative unit: Norsk Regnesentral (NR)
Title of case study: Geophysical Inversion to Geology (GIG)
Period when the underpinning research was undertaken: 2012 –
Period when staff involved in the underpinning research were employed by the submitting institution: 2012 –
Period when the impact occurred: 2012 –

1. Summary of the impact (indicative maximum 100 words)

In hydrocarbon exploration, seismic data plays a crucial role in mapping potential hydrocarbon deposits beneath the seabed. It guides the subsequent drilling of wildcat and appraisal wells to confirm the reserves. In hydrocarbon field development and production, seismic data is also important for planning production wells and infill drilling to accelerate and enhance expected hydrocarbon recovery.

Our research focuses on developing methods for predicting the subsurface lithology and pore fluids from seismic data, using a Bayesian statistical framework. The Bayesian framework helps reduce uncertainty of initial beliefs by observing relevant data. This improves the decision-making process in oil and gas companies, mitigating risks in exploration and enhancing reservoir performance monitoring during production.

2. Underpinning research (indicative maximum 500 words)

The project has developed approximations that are computationally attractive while maintaining a level of predictability of litho-fluid properties. Our main challenge lies in the non-uniqueness of the inversion of seismic data, which means that several different candidate subsurface models (i.e. combinations of different lithologies and fluids) can produce similar seismic responses. In principle, the idea is simple: Test all possible subsurface models against the seismic data. However, the vast number of possible combinations makes this approach infeasible.

Instead, we have developed a smarter approach that only uses relevant candidate models and conducts local comparisons with the seismic data. In practice, we use geologic constraints as input to guide the inversion process, reducing the number of candidate models. To rank the comparison with seismic data, we assume that synthetic seismic of candidate models can be modelled according to multinormal Gaussian distributions. The link between candidate models and seismic data hinges on elastic rock parameters, like sound velocities and densities, along with an approximation of sound wave reflectivity in the earth, often referred to as the Aki and Richards equations.

From the inversion, we can estimate the best candidate model as well as the full probability distribution for all the other models. Since we know the full distribution, we can also generate statistical summaries like layer thickness, the likelihood of specific rock types, as well as probability distributions of reservoir rock properties like porosity and clay content. To accomplish the latter, we need prior information about the reservoir properties and their

relationship to the elastic rock parameters, which is provided by input probability distributions.

Recently, we have extended the inversion model to analyse two seismic data sets simultaneously. During hydrocarbon production, repeated seismic surveys are frequently applied to monitor the performance of the reservoir. Companies spend a lot of time analysing and interpreting these data, and we are currently investigating if our approach can be used to distinguish between regions that have undergone production and those that have not. Initial testing is very promising, and we anticipate further developments in this area in the future.

The project was initiated in 2010 and our research is still ongoing. The study initially began as a collaboration between NR and Statoil (now Equinor). In 2016, we received permission from Statoil to pursue collaborations with other oil companies, thus enhancing the project's impact and funding. This led to the founding of a consortium of initially three partners, but now comprises eight members. The members are: AkerBP, ConocoPhillips, Equinor, OMV, Sval energi , TotalEnergies, VårEnergi, and Wintershall Dea.

While the level of scientific contributions has varied among companies, a few people have made significant contributions and are listed below.

The following members of SAND have contributed to this research:

- Petter Abrahamsen (Research director, SAND)
- Eyvind Aker (Chief research scientist, 2016-2024)
- Daniel Barker (Senior research scientist, 2017-)
- Torstein Mæland Fjeldstad (Senior research scientist, 2020-)
- Bjørn Fjellvoll (Senior research scientist)
- Ragnar Hauge (Assistant research director, SAND)
- Heidi Kjønsberg (Senior research scientist)
- Odd Kolbjørnsen (Senior research scientist, 2002-2014)
- Carl-Inge Colombo Nilsen (Senior research scientist, 2018-)
- Per Røe (Chief research scientist)
- Charlotte Semin-Sanchis (Senior research scientist, 2016-)

Significant contributions to the GIG consortium from individuals outside NR:

- Arild Buland (Equinor)
- Øyvind Skjæveland (Equinor)
- Øyvind Kjøsnes (AkerBP)
- Odd Kolbjørnsen (AkerBP, but worked at NR until 2014)

3. References to the research (indicative maximum of six references)

Jullum, M., and Kolbjørnsen, O. (2016). A Gaussian-based framework for local Bayesian inversion of geophysical data to rock properties. *Geophysics*, **81**, R75-R87. https://doi.org/10.1190/geo2015-0314.1

Kolbjørnsen, O., Buland, A., Hauge, R., Røe, P., Jullum, M., Metcalfe, R.W., and Skjæveland, Ø. (2016). Bayesian AVO inversion to rock properties using a local neighborhood in a spatial prior model. *The Leading Edge.* http://dx.doi.org/10.1190/tle35040431.1

Skjæveland, Ø. (2018). Making Use of the Lithology Domain to Constrain Prestack Seismic Inversion to Lithology. *80th EAGE Conference and Exhibition*, Extended Abstracts. https://doi.org/10.3997/2214-4609.201801080

Aker, E., Kjønsberg, H., Røe, P., and Kjøsnes, Ø. (2018). Probabilistic inversion into lithology and fluid classes in the North Sea – Comparison of one- and two-step approach. *80th EAGE Conference and Exhibition*, Extended Abstracts. https://doi.org/10.3997/2214-4609.201801899

Aker, E., Thiebaud, J., and Røe, P. (2020). Probabilistic AVO Inversion of Transversely Isotropic Medium for Better Characterization of North Sea Oxfordian Turbidite Reservoir. *1st EAGE Conference on Seismic Inversion*, Extended Abstracts. https://doi.org/10.3997/2214-4609.202037010

Kolbjørnsen, O., Buland, A., Hauge, R., Røe, P., Ndingwan, A.O., and Aker, E. (2020). Bayesian seismic inversion for stratigraphic horizon, lithology, and fluid prediction. *Geophysics* **85**, R207-R221. https://doi.org/10.1190/geo2019-0170.1

Aker, E., Kjønsberg, H., Fawad, M., and Mondol, N.H. (2021). Estimation of thickness and layering of Johansen and Cook sandstones at the potential CO2 storage site Aurora. *Conference on CO_2 Capture, Transport and Storage*, Trondheim, Norway in *SINTEF proceedings*, **7**. https://hdl.handle.net/11250/2779937

Kjønsberg, H., Hauge, R., Ndingwan, A.O., Kolbjørnsen, O. (2022). Time-lapse Bayesian AVO inversion applied to the Edvard Grieg field in the North Sea. *2nd International Meeting for Applied Geoscience & Energy*, Extended Abstracts. https://doi.org/10.1190/image2022-3745774.1

Semin-Sanchis, C., and Kolbjørnsen, O. (2023). Sampling-Free Bayesian Inference for Local Refinement in Linear Inversion Problems With a Latent Target Property. *IEEE Trans. Geosci. and Remote Sens.*, **61**, 5916014, https://doi.org/10.1109/TGRS.2023.3301717

4. Details of the impact (indicative maximum 750 words)

The software we are developing has been implemented into the workflow of the consortium companies' when conducting quantitative seismic inversion. This involves predicting lithologies, and pore fluid and reservoir properties directly from seismic data. We offer a user-friendly graphical interface for setting up, running, and performing basic quality checks of the inversion process. Some companies use this interface, but an increasing amount use the software through a professional software package with a more advanced graphical user interface and data management for analysing and storing the results.

The GIG consortium has established agreements with Sharp Reflection, who has access to our source code in C++, and Cegal, who has access to our application programming interface (API) in C#. Sharp Reflection is directly incorporating our C++ code into their professional software suite designed for analysing pre-stack angle gathers (PSPRo). PSPro is license-based and available to customers worldwide. Cegal has developed a plugin for the Petrel geology and modelling software, exclusively for GIG consortium members. As a result, the user base and impact of our software is significant and continues to expand.

5. Sources to corroborate the impact (indicative maximum of ten references)

The Norwegian University of Science and Technology (NTNU) has been running the Uncertainty in Reservoir Evaluation project (URE), which is supported by the Research Council of Norway (RCN) and various oil companies, for many years. The project investigates similar challenges and we have recruited several of their PhD candidates to our team.

For more information, please see: https://wiki.math.ntnu.no/ure.

Commercial software and consultancy services offered by Ikon Science, Cegal, and Qeye aim to address the same problems, but we assert that our solution is superior, both in terms of speed and accuracy.

Ikon Science:
https://www.ikonscience.com/cptresource/a-new-joint-impedance-and-facies-inversion/
Cegal:
https://www.cegal.com/en/software/geoscience/blueback-odisi
Qeye:
https://www.qeye-labs.com/inversion-solutions/direct-probabilistic-inversion/

Norsk Regnesentral (NR), case no. 3

Institution: Norsk Regnesentral (NR)
Administrative unit: Norsk Regnesentral (NR)
Title of case study: Transformation of image analysis by deep learning
Period when the underpinning research was undertaken: 2013-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2013-2022
Period when the impact occurred: 2013-2022

1. Summary of the impact

Image analysis and machine learning has gone through a transformation with the emergence of deep learning (DL) applications for image data. The turning point came in 2012 when DL started to revolutionise computer vision. NR began experimenting with deep learning across various applications in 2013, and soon discovered its effectiveness, and how it typically outperforms conventional methods. From 2018 onwards, DL has been integral to our research, and has firmly established its dominance in most of our projects. This has marked a rare paradigm shift within our well-established field of research and development (R&D).

Today, NR continues to contribute to advancing R&D in image analysis, machine learning and Earth observation (EO), and our reach extends to a wide range of applications, including healthcare, transport, ocean, climate and environment, infrastructure, and general mapping and monitoring tasks.

2. Underpinning research

The transformation outlined above had a significant impact on both NR and our partners working with complex image data. In 2013, when our experiments began, we ventured into deep learning with the aim of recognising handwritten digits from old text documents. We applied these methods in two projects, one involved transcribing old census forms from 1891 for the Norwegian Historical Population Register (HPR), and the other focused on transcribing cause of death registers for the Norwegian Institute of Public Health (NIPH). Chief Research Scientist Line Eikvil led this work in 2013, and it was published alongside other results in 2015 (Thovaldsen et al.).

Following that, we went on to explore convolutional neural networks (CNNs) to detect seals in aerial photos over sea ice, estimate skeletal age from MRI images, and to identify small animals captured by wildlife cameras. This work, conducted by Eikvil and Senior Research Scientist, Arnt-Børre Salberg between 2013 and 2014, demonstrated our ability to tackle problems and images that had been considered too challenging with conventional methods. These successes led to further DL research, focusing our efforts on four overarching application areas: medical image analysis, Earth observation, marine sciences, and energy.

Our first impactful paper in the EO community addressed the application of a fully convolutional neural network to perform pixel-wise thematic mapping of EO images (Kampffmeyer et al. 2016). This pioneering work marked the first of its kind and has since been cited more than 600 times (Google Scholar, 2024). The paper formed the basis for a number our semantic segmentation research applications in subsequent years and has played a crucial role in our collaboration with UiT The Arctic University of Norway.

Within medical image analysis, an important part of our transformation began in 2016 through our collaboration with GE Vingmed AS. Here, we applied DL to analyse cardiac ultrasound data, ushering GE Vingmed into the DL era. Our research led to DL-based methods for cardiac view recognition and cardiac measurements (Gilbert et al. 2019; Gilbert et al. 2021). In 2017, a collaboration with the Cancer Registry of Norway was initiated, focusing on machine learning for mammographic screening. This has yielded methods for breast cancer detection based on weak labels, that can locate and identify cancerous areas with exceptional accuracy.

In 2018, we authored a pioneering paper that applied deep learning to the mapping of cultural heritage remains (Trier et al.). It was one of the first papers of its kind, and its successful approach led to the development of the 'Cultsearcher' tool, which is now widely used by Norwegian archaeologists for cultural heritage mapping.

In the marine sector, we were the first to apply DL to classify acoustic echosounder data (Brautaset et al. 2020). The paper, a result of the project COGMAR, strengthened our collaboration with the Institute of Marine Research (IMR) and was instrumental in establishing research activity for marine science at NR. Subsequent papers followed, which led to the establishment of CRIMAC, a Centre for Research-based Innovation (SFI), with NR as a key research partner.

In 2021, we introduced a novel network architecture that combines graph neural networks, variational autoencoders and CNNs (Liu et al. 2021). The network provides a 'global view' with significantly less computations than the popular transformer architectures. For NR, this was a crucial steppingstone that paved the way for future work on graph networks, ultimately enabling the project KnowEarth, funded by the Research Council of Norway (RCN).

The paper, 'Forest mapping and monitoring in Africa using Sentinel-2 data and deep learning,' (Waldeland et al. 2022) marked our first application of deep learning for continental-scale mapping. Another internationally pioneering work, the paper estimated tree heights from optical satellite date using DL. The research was influential for the European Space Agency's (ESA) adoption of deep learning for EO data, and it has been key for NR's further collaboration with the agency. Moreover, it equipped NR with the expertise needed to conduct large-scale mapping with deep learning techniques.

3. References to the research

(NR research scientists shown in **bold**, part time scientists shown in *italics*.)

Olav Brautaset, **Anders Ueland Waldeland**, Espen Johnsen, Ketil Malde, **Line Eikvil**, **Arnt-Børre Salberg** and Nils Olav Handegard (2020). Acoustic classification in multifrequency echosounder data using deep convolutional neural networks. ICES Journal of Marine Science, 77(4), 1391-1400. https://doi.org/10.1093/icesjms/fsz235

Andrew David Gilbert, **Marit Holden**, **Line Eikvil**, Svein Arne Aase, Eigil Samset and Kristin Mcleod (2019). Automated left ventricle dimension measurement in 2D cardiac ultrasound via an anatomically meaningful CNN approach. In Smart Ultrasound Imaging and Perinatal, Preterm and Paediatric Image Analysis: First International Workshop, SUSI 2019, and 4th International Workshop, PIPPI 2019, Held in Conjunction with MICCAI 2019, Shenzhen, China, October 13 and 17, 2019, Proceedings 4 (29-37). Springer International Publishing. https://doi.org/10.48550/arXiv.1911.02448

Andrew David Gilbert, **Marit Holden**, **Line Eikvil**, Mariia Rakhmail, Aleksandar Babic, Svein Arne Aase, Eigil Samset and Kristin Mcleod (2021). User-Intended Doppler Measurement Type

Prediction Combining CNNs With Smart Post-Processing. IEEE Journal of Biomedical and Health Informatics, 25, 6, 2113-2124. https://doi.org/10.1109/JBHI.2020.3029392

Google Scholar. (accessed 2024, 26.01). *Semantic segmentation of small objects and modeling of uncertainty in urban remote sensing images using deep convolutional neural networks.* Google Scholar. https://scholar.google.com

Michael Kampffmeyer, **Arnt-Børre Salberg** and *Robert Jenssen* (2016). Semantic segmentation of small objects and modeling of uncertainty in urban remote sensing images using deep convolutional neural networks. In 2016 IEEE Conf. Computer Vision Pattern Recognition Workshops (CVPRW), Las Vegas. https://doi.org/10.1109/CVPRW.2016.90

Qinghui Liu, *Michael Kampffmeyer*, *Robert Jenssen* and **Arnt-Børre Salberg** (2021). SCG-Net: Self-Constructing Graph Neural Networks for Semantic Segmentation. International Journal of Remote Sensing, 42(16), 2021. https://doi.org/10.48550/arXiv.2009.01599

Thorvaldsen, G., Pujadas-Mora, J. M., Andersen, T., **Line Eikvil**, Lladós, J., Fornés, A., & Cabré, A. (2015). A tale of two transcriptions. Machine-assisted transcription of historical sources. Historical life course studies, 2, 1-19. https://hlcs.nl/article/view/9355/9854

Øivind Due Trier, Arnt-Børre Salberg and Lars Pilø (2018). Semi-automatic mapping of charcoal kilns from airborne laser scanning data using deep learning. In CAA2016: Oceans of Data. Proceedings of the 44th Conference on Computer Applications and Quantitative Methods in Archaeology (pp. 219-231). Oxford: Archaeopress. https://doi.org/10.1016/j.jag.2020.102241

Anders U. Waldeland, Øivind Due Trier and **Arnt-Børre Salberg** (2022). Forest mapping and monitoring in Africa using Sentinel-2 data and deep learning. International Journal of Applied Earth Observation and Geoinformation, 111, 13 pp. https://doi.org/10.1016/j.jag.2022.102840

4. Details of the impact

Our deep learning journey began in 2013, with a project tasked with recognising handwritten numbers in Norwegian census forms from 1891. This was the first time we witnessed the strength of CNNs, and it prompted us to start beginning building competence in this area.

We then went on to explore the use of CNNs for animal detection in aerial and wildlife photos, and to estimate skeletal ages from MRIs. We discovered we were capable of tackling issues that were previously considered insurmountable with conventional methods. Inspired by this success, we applied CNNs to even more complex image data, detecting charcoal kilns from lidar data. Once again, DL proved tremendously successful, transforming the way our clients work with lidar data to uncover cultural heritage sites and monuments.

In 2015, we continued investing in our expertise, acquiring our first graphical processing unit (GPU) customised for DL image analysis. We shared our research experiences online, showcasing practical DL applications, and authored a popular science article in Norwegian which presented this 'revolution in machine learning' (Eikvil & Salberg, 2016). We also held multiple presentations at the University of Oslo and various data science meetups, raising national awareness about the possibilities of DL.

Our increased visibility contributed to the collaboration with GE Vingmed in 2016, which led to the INCUS project. We developed methods for their cardiovascular ultrasound scanner, resulting in

several publications and the implementation of DL-based tools in their scanners. GE Vingmed's Chief Engineer, Erik Steen, has stated that NR has ushered the company into the world of AI.

That same year, we began a collaboration with Professor Robert Jensen at the Machine Learning Group (MLG) at UiT, aiming to advance the field of deep learning for image analysis and engage academic researchers. An early result was a pioneering paper that applied fully convolutional neural networks for semantic segmentation of Earth observation images (Kampffmeyer et al. 2016).

In 2017, Arnt-Børre Salberg's presentation on 'AI & deep learning: what´s next in Earth observation' at Spaceport Norway caught the attention of ESA, leading to a project where we mapped tree heights in the entire African continent using DL. Notably, this was one of the first DL projects at the ESA Phi-lab. After that, ESA launched the project 'AI for Arctic' (AI4EO), with NR as its designated leader.

Inspired by the mapping capabilities of DL, the Directorate for Cultural Heritage initiated a project to develop a DL-based tool for mapping cultural heritage remains with laser scanner data. This tool is now used by county archaeologists to map objects like charcoal kilns, grave mounds, and pitfall traps in high-resolution airborne lidar data (Trier et al. 2018).

We were contacted by Equinor (then Statoil) in 2016 with a request to explore the use of DL-based methods for analysing seismic data. A project was quickly initiated, and it remains one of our most successful projects to date, largely transforming the way interpretation of seismic data is performed. Since then, we have worked with a range of entities to solve their image analysis challenges including ongoing collaborations with IMR and the Cancer Registry of Norway.

These projects and collaborations, along with our experiences with the challenges of deep learning for complex image data, led us to apply for funding from the RCN for an SFI in collaboration with UiT and UiO. Our application was approved, and the centre, Visual Intelligence, was established in 2020. The centre includes eight user partners from medicine, marine sciences, the energy sector, and Earth observation. The objective is to provide cutting-edge solutions for complex image analysis by harnessing the power of deep learning to answer innovation needs across application areas and domains. Simultaneously, the Norwegian Institute for Water Research (NIVA) secured funding for SeaBee, the research infrastructure project for drone-based research. In this project, we are responsible for developing the AI engine for analysing drone images.

Our commitment to making an impact in deep learning continues. We recently secured an ESA tender to develop multi-modal foundation models for EO, and we anticipate that the results of this project will have huge implications for the EO community, significantly influencing the design of downstream tasks. We believe experience gained from this project will also be harnessed to drive impacts in many of our other innovation areas.

5. Sources to corroborate the impact

Line Eikvil; Arnt Børre Salberg; En revolusjon innen maskinlæring journal Teknisk Ukeblad, (ISSN 0040-2354), 2016. Kronikk

Line Eikvil. Norske forskere utvikler en ny metode for å finne brystkreft. Intervju forskning.no september 2020. https://www.forskning.no/helse/norske-forskere-utvikler-en-ny-metode-for-a-finne-brystkreft/1736651

Line Eikvil. Google har utviklet kunstig intelligens som gjenkjenner brystkreft bedre enn radiologer - Kreftregisteret og Norsk Regnesentral lager norsk variant. Teknisk Ukeblad, januar 2020. https://www.tu.no/artikler/google-har-utviklet-kunstig-intelligens-som-gjenkjenner-brystkreft-bedre-enn-radiologer-br/482168?hide_paid_offers=true

AI-based view recognition for cardiac ultrasound: https://www.gehealthcare.com/-/jssmedia/gehc/us/files/products/ultrasound/vivid/redesign/resources/whitepaper_the-role-of-artificial-intelligence__jb20789xx.pdf?rev=-1

DELI – Deep Learning Interpretation of seismic data: https://www.sodir.no/globalassets/2-force/2019/documents/2019/hackathon/equinor-jens-grimsgaard---dl-horizon-interpretation---force-sep-2019.pdf

AI-based solution for acoustic classification in multifrequency echosounder data: https://academic.oup.com/icesjms/article/77/4/1391/5712978

CultSearcher cultural heritage mapping software tool: https://www.riksantikvaren.no/wp-content/uploads/2023/01/Kunnskapsgrunnlag-for-bevaringsstrategier.pdf

Coastal mapping tools for environmental protection: https://seabee.no/applications/

AI-based solutions for breast cancer screening: https://journals.uio.no/NMI/article/view/10459

Nature intervention detection tool: https://www.miljodirektoratet.no/publikasjoner/2023/mai-2023/driftspilot-veideteksjon-metodeforbedringer-i-2022/

[Norsk Regnesentral, Norsk Regnesentral] [4]

Institution: Norsk Regnesentral
Administrative unit: Norsk Regnesentral
Title of case study: Digital inkludering – Digital Inclusion
Period when the underpinning research was undertaken: 2012-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2012 - current
Period when the impact occurred: 2012 - current

1 Summary of the impact (indicative maximum 100 words)

The nationally leading research team in digital inclusion has had substantial impact beyond academia. Their research has demonstrated tangible benefits of digital inclusion across diverse user groups, prompting public and private sectors to develop more accessible products, services, and systems.

The team has actively contributed to knowledge dissemination through participation in national and international seminars and conferences. They also host a meetup group covering digital inclusion and universal design of ICT, with nearly 1,000 members at the time of writing. Their work spans across sectors, domains, and technologies. Through close collaboration with industry, governmental and non-governmental organisations, their research continues to actively shape policy and society.

2 Underpinning research (indicative maximum 500 words)

This research case comprises a body of work produced through more than fifty projects conducted between 2012 and 2022. The work is characterised by projects with a focus on digital inclusion in close collaboration with various user groups, and public and private actors. The recurring project themes have been uncovering digital barriers among various user groups, identifying the consequences to individuals and society of digital exclusion, and developing and evaluating methods and tools to help reduce or eliminate digital barriers.

The key research insights and findings have been:

a) Identifying non-compliance among digital service providers in meeting legal requirements for universally designed solutions, and uncovering digital barriers experienced by various user groups. User groups include the elderly, children and youth with disabilities, people with visual impairments, people who are hard of hearing, people with dyslexia, people with autism, people with cognitive disabilities, people with chronic conditions, people with foreign cultural backgrounds and other minorities.

b) Developing methods and documenting best practices for user and stakeholder engagement and participatory approaches to design and development of inclusive and accessible digital technologies.

c) Contributing to standards, guidelines, and tools for designing inclusive technology. This work encompasses a range of different technologies, such as web technologies, mobile interfaces, the Internet of Things (IoT), self-service machines, smart homes, authentication and identity management, online questionnaires, extended reality (XR, AR, VR and MR) and social robots. It

also covers different domains including e-voting, public and private citizen services, education, working life, health- and welfare technology, as well as museums and tourism.

d) Conducting assessments of social and economic implications of digital access, examining how digital inclusion or exclusion may affect democracy, societal participation, and working life. The group has also produced valuable insights into the development of digital skills for older people and people with visual impairments, shedding light on various aspects of organisation, prevalence, and compliance with legal standards.

Contributions to this research were made by:

- Kristin Skeide Fuglerud (2012-2022, chief research scientist)
- Ivar Solheim (2012-2020, chief research scientist)
- Till Halbach (2012-2022, senior research scientist)
- Trenton Schulz, (2012-2018 and 2021-2022, senior research scientist, PhD leave: 2018- 2021)
- Ingvar Tjøstheim (2012-2020, senior research scientist)
- Aleksander Bai (2015-2019, senior research scientist)
- Heidi Mork (2015-2016, senior research scientist)
- Siv Tunold (2019-2020, research scientist)
- Joschua Thomas Simon-Liedke (2020-2022, senior research scientist)

3 References to the research (indicative maximum of six references)

The work has been conducted over the ten-year period. Below, we have selected examples of peer-reviewed publications corresponding to the numbered impact list above.

a) Digital barriers, mechanisms and consequences of digital inclusion or exclusion

Fuglerud, K.S.; Røssvoll, T.Halbach.; «An evaluation of Web-based voting usability and accessibility.» in Universal Access in the Information Society. 11 (4): 359-373. 2012/11/01, 2012. URL: http://dx.doi.org/10.1007/s10209-011-0253-9
(journal article, 2 NR-researchers, cited by 54)

b) Stakeholder engagement and participatory approaches

Fuglerud, K. S., Schulz, T., Janson, A. L., & Moen, A. (2020). Co-creating Persona Scenarios with Diverse Users Enriching Inclusive Design. In M. Antona & C. Stephanidis (Eds.), Universal Access in Human-Computer Interaction. Design Approaches and Supporting Technologies (Vol. 12188, pp. 48–59). Springer International Publishing. https://doi.org/10.1007/978-3-030-49282-3_4
(Conference paper, 2 NR researchers, cited by 28)

c) Standards, guidelines, tools, technologies, and best practices of accessibility

Halbach, T., Schulz, T., Leister, W., & Solheim, I. (2021). Robot-Enhanced Language Learning for Children in Norwegian Day-Care Centers. Multimodal Technologies and Interaction, 5(12). https://doi.org/10.3390/mti5120074
(Journal-article, 4 NR-researchers, 11 citations)

d) Impact assessment for individuals and society

Bai, A., Mork, H. C., & Stray, V. (2017). A cost-benefit analysis of accessibility testing in agile software development: Results from a multiple case study. International Journal on Advances in

Software, 10(1 & 2), 96–107. https://www.duo.uio.no/handle/10852/70786
(Journal article, 1 NR-researcher, 32 citations)

Fuglerud, K. S., Tunold, S., Kjæret, K. (2021). Social Contact for Older People with Visual Impairment Through Mastery of Smartphones: Barriers and Suggested Solutions. I Universal Design 2021: From Special to Mainstream Solutions (s. 415–428). IOS Press. https://doi.org/10.3233/SHTI210417
(Conference paper, 2 NR-researchers, 5 citations)

Halbach, T., Fuglerud, K. S., Fyhn, T., Kjæret, K., & Olsen, T. A. (2022). The Role of Technology for the Inclusion of People with Visual Impairments in the Workforce. Universal Access in Human-Computer Interaction. User and Context Diversity: 16th International Conference, UAHCI 2022, Held as Part of the 24th HCI International Conference, HCII 2022, Virtual Event, June 26 – July 1, 2022, Proceedings, Part II, 466–478. https://doi.org/10.1007/978-3-031-05039-8_34
(Conference paper, 2 NR-researchers, 2 citations)

4. Details of the impact (indicative maximum 750 words)

In addition to individual results, the impact also results from numerous reports, presentations, lecture, and dissemination activities that make the research accessible to many stakeholders within this domain in Norway.

Identifying digital barriers was an important reason for the assignment from the Ministry of Local Government to assess the Norwegian e-voting trial and its consequences for citizens with disabilities. In addition to scientific publications, this resulted in an evaluation report (pp 85-158) that was included in the knowledge basis in Prop 52 L (2012-2013), Proposing changes to the Election Act and the Local Government Act [Proposal to the Parliament (draft law decision), (See page 50)]. In the consideration of changes to the Election Act (Innst. 431 L (2022-2023), a unanimous committee emphasised the importance of providing access to secret ballots for the blind and visually impaired, suggesting that this could be addressed through electronic voting. This viewpoint was influenced, among other sources, by input from the Norwegian Association of the Blind and Partially Sighted (NABP), which referred to NR's evaluation report.

In 2015, we led a project commissioned by the Norwegian Directorate for Children, Youth and Family Affairs (Bufdir) to explore scenarios for a universally designed Norway by 2025. The project engaged stakeholders from various sectors and resulted in the report Room for Action for a Universally Designed Society. The project was part of the government's action plan for universal design, serving as a basis for a modern policy that addresses the ageing population and describes effects and the innovation potential of universal design.

An evaluation of the action plans for universal design (see p. 122) identified schools as a key area for follow-up, leading Bufdir to initiate the investigation, "Roadmap for universally designed local schools 2030." The legislation regarding universally designed ICT was expanded to also include ICT in education from 2018. The work has arguably contributed to raising knowledge awareness about the importance of universal design in schools, and thus influencing policy and legislation in this domain.

Between 2019 and 2022, several of our projects focused on digital inclusion in the workplace and examined the effect of implementing requirements of universal design in this area. In addition to engagement in various media, work from the project "ICT in the Employment of the Visually Impaired" was presented to the State Secretary in 2019. The Ministry of Local Government and Modernisation and the Ministry of Culture and Equality also referred to the report in their announcement to investigate socioeconomical consequences of implementing universal design

requirements of ICT in the workplace. On behalf of Bufdir, NR and other organisations are presently partnered to examine relevant issues.

We have worked on several projects addressing how digitisation affects opportunities for equitable digital healthcare services. In 'Video for all' (2022-2023), Sunnaas Rehabilitation Hospital, Norsk Helsenett and NR developed an action plan for inclusive video consultations in the healthcare sector as well as video resources for how to implement more accessible video consultations. Sunnaas is a major Norwegian hospital, and Norsk Helsenett operates helsenorge.no, the official web solution for access to healthcare services for all citizens in Norway.

With funding from the Norwegian Directorate of Health, and in collaboration with NABP, we have worked on aspects related to visually impaired seniors, one of the most digitally excluded and socially isolated groups in Norway. The project ran between 2019 and 2022, and several reports shed light on aspects of digital exclusion, opportunities for inclusion, and the importance of basic digital training, tailored specifically for this group. Research outcomes include the development of multiple resources for Norwegian municipalities [see pp. 56-58]. NABP also used research findings in their input to the Norwegian government's national strategy for increased digital participation and competence in the population.

In addition, Digital Inclusion continues to actively engage with the public through a variety of channels. This includes presentations at seminars and conferences, as well as participation in debate panels. We host a meetup group of nearly 1,000 members and provide webpages with resources for practitioners. Our engagement in the national UNIKT network and a forum for universal design in ICT further extends the group's reach. To raise awareness and knowledge about research areas and activities, we maintain an active social media presence, participate in podcasts, and create and distribute newsletters to subscribers.

Publications from our researchers are used as curriculum material in university education. Moreover, our researchers contribute to the development of new professionals in the field, often serving as guest lecturers, supervisors, and examiners at master's and PhD level. As of 2022, two researchers held part-time professorships at Norwegian universities.

5. Sources to corroborate the impact (indicative maximum of ten references)

Reports:

Fuglerud, K. S., & Tjøstheim, I. (2012); E-valg, tilgjengelighet for velgere med nedsatt funksjonsevne. [Eng: E-voting, accessibility for voters with disabilities] In Seegaard, S., & Saglie, J. (Eds.) *Evaluering av forsøket med e-valg 2011: Tilgjengelighet for velgere, tillit, hemmelig valg og valgdeltakelse.* (pp. 85–159). Institutt for samfunnsforskning. ISBN (pdf): 978-82-7763-389-3

NS 11040:2013 Universell utforming — Brukermedvirkning og IKT [Eng: Universal design and user participation – ICT]. Fuglerud, K. S. was the committee leader. Standard Norway. https://online.standard.no/ns-11040-2013

Dietz, J., Fuglerud, K.S, & Solheim, I. (2016); Handlingsrom for et universelt utformet samfunn: Prosjektrapport. [Eng: Room for Action for a Universally Designed Society: Project Report], (NR-Report no 1033, 71 pp.). Oslo: Norsk Regnesentral ISBN 978-82-539-0543-3

Fuglerud, K.S.; Kjæret, K. (2021); iStøtet – IT-støtte for synshemmede eldre: Inkludering i informasjonssamfunnet – motivasjon, opplæring og oppfølging. [Eng: IT support for older visually impaired people: Inclusion in the information society – motivation, training, and follow-up] (NR-report no. 1053, 47pp.) Oslo: Norsk Regnesentral: ISBN 978-82-539-0558-7.

Fuglerud, K.S., Fyhn, T., Halbach, T., Kjæret, K., & Olsen, T.A. (2021); Teknologi og inkludering av personer med nedsatt syn i arbeidslivet: Kunnskapsoppsummering [Eng: Technology and inclusion of people with visual impairments in working life: Knowledge summary]. (NR-Report no. 1054, 40 pp.) Oslo: Norsk Regnesentral: ISBN 978-82-539-0564-8,

Interviews, panel debates and presentations

Halbach, Till. (2020, February 4); Undersøkelse: Manglende tilrettelegging gjør at blinde slutter i jobben [Eng: The lack of digital accessibility leads to blind individuals quitting their jobs]. Interview by A. Naper in Dagens Perspektiv - om ledelse og samfunnsstyring. https://dagensperspektiv.no/arbeidsliv/2020/far-ikke-nok-tilrettelegging

Halbach, T., Fuglerud, K.S. (2021, May 28); Universal Design for Inclusion and Sustainability: from Public Services to Virtual Reality» at the First Annual Universal Design Day, Online Zoom: NAV. https://www.inclusivecreation.com/udday

Halbach, T. (2022, March 2); Slik lar du brukerstemmer for tjenestene dine bli hørt [This is how you let user voices for your services be heard]. Presentation at Public World, Organized by Den norske dataforening. https://event.cw.no/publicworld21/foredragsholdere

Fuglerud, K.S; (2022, August 17); Arendalsveka 2022. Videoblogg: Åtte på gata om digitalt utanforskap - Kristin Skeide Fuglerud [Eng: Video blog: Eight on the street about digital exclusion - Kristin Skeide Fuglerud]. Video interview by Malin Rygg, The Authority for Universal Design of ICT, the Norwegian Digitalisation Agency. https://www.uutilsynet.no/uubloggen/videoblogg-atte-pa-gata-om-digitalt-utanforskap-kristin-skeide-fuglerud/1381

Fuglerud, K.S; Thon, B.E; Lippestad, G.; Jaffery, L. (2022, August 19); Digitalisering: Økt deltagelse eller økt utenforskap? [Eng: Digitalization: Increased participation or increased exclusion? Panel debate moderated by Gjuvsland, E.R. Norsk Regnesentral and IKT-Norge, Arendal. https://ikt-norge.no/arrangementer/arendalsuka-2022-torsdag-18-8/

Fuglerud, K.S; (2022, September 30); Ubrukt kompetanse: har Norge råd til det? [Eng: Unused competence: Can Norway afford it?] The conference «Inkluderende arbeidsliv», [Eng: Inclusive working life]. Organized by NAV and the Norwegian Association for the Blind and Partially Sighted. Quality Hotell, Tønsberg. https://www.youtube.com/watch?v=uUo5d9-siao

NTNU Department of Engineering Cybernetics – impact case 1

Institution: Norwegian University of Science and Technology (NTNU)
Administrative unit: Department of Engineering Cybernetics (ITK)
Title of case study: Autonomous urban passenger ferries
Period when the underpinning research was undertaken: 2016-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2016-2022
Period when the impact occurred: 2019-2022

1. Summary of the impact (indicative maximum 100 words)

In 2016, NTNU started research on autonomous passenger ferries for urban waterways, which makes it possible to use small self-driving and electric ferries to transport people along waterways instead of building bridges, and also alleviating road traffic. This cross-disciplinary research has since involved over 300 people including professors, postdocs, researchers, PhD candidates, MSc students, BSc students and partners from both industry companies and the public sector, to achieve what was the world's first full-scale trial operation of an autonomous urban passenger ferry in the Canal in Trondheim over three weeks in September-October 2022. Prior to this trial operation, the core research group at NTNU made the spinoff company Zeabuz in December 2019, which today employs 28 people and currently is the world's leading company of its kind. In the summer of 2023, Zeabuz together with the transportation company Torghatten, launched the world's first commercial autonomous passenger ferry for urban waterways in Stockholm, Sweden. Employees at the Department of Engineering Cybernetics (ITK) have played a key role in this unique journey by developing the core autonomy technology required.

2. Underpinning research (indicative maximum 500 words)

The autonomous ferry research activity starting in 2016 did so within the context of the ecosystem of researchers associated with the large "NTNU AMOS" SFF research centre (2013-2023) focusing on autonomy technology for different types of vehicles, and NTNU's first major research project on autonomous ships "Autosea" (2015-2019), both funded by the Research Council of Norway.

In 2016, NTNU funded the construction of the first experimental ferry prototype "milliAmpere1", which was finished and put on water in 2017. In 2018, NTNU funded the first major dedicated research project to this field called "Autoferry" (2018-2024), with 8 PhD candidates from different research disciplines such as engineering cybernetics, marine technology, cybersecurity and industrial design. In 2020, the second ferry prototype "milliAmpere2" was constructed and put on water. Also in 2020, the "NTNU Shore Control Lab" was established, where researchers can remotely monitor and control a single or multiple ferries. Other minor lab infrastructure elements are also part of the total research infrastructure, which today is world-leading and unique.

The research has spanned multiple research projects, in a large cross-disciplinary activity across four key NTNU departments, namely Engineering Cybernetics, Electronic Systems, Design and Marine Technology. The activity has also included teaching courses at NTNU (e.g. the cross-disciplinary course "Experts in Team") and supervision of a large number of MSc and BSc students. Too many researchers to name here have been involved over the years.

Some key researchers from ITK:

- Morten Breivik, Head of Department (2013-2021) and Associate professor (2021-)

- Edmund F. Brekke, Associate professor (2013-2023) and Professor (2023-)
- Tor Arne Johansen, Professor the entire period
- Annette Stahl, Associate professor (2016-2023) and Professor (2023-)
- Bjørn-Olav Holtung Eriksen, PhD candidate (2015-2019) and postdoc (2019-2020)
- Erik F. Wilthil, PhD candidate (2015-2019) and postdoc (2019-2020)
- Inger B. Hagen, PhD candidate (2017-2022)
- Emil H. Thyri, PhD candidate (2019-2022)
- Øystein K. Helgesen, PhD candidate (2019-2023)

Specifically, advanced motion planning, collision avoidance and motion control algorithms have been developed and experimentally tested in full scale using the ferry prototypes with excellent results in the Canal in Trondheim. A multi-sensor tracking system using ferry-based sensors such as radar, lidar and camera has also been developed, which feeds inputs to the motion control systems about what is going on around the ferry. These control and sensor systems are the core of the autonomy system of the ferries, and have been developed by researchers and students from ITK. Other departments have spearheaded the simultaneous development of human-machine interfaces, remote monitoring and control functionality, and communication and cybersecurity architectures.

The FORNY commercialization project aFerry (2019-2020) resulted in a more industrially robust autonomy technology, which was licensed to the spinoff company Zeabuz which was established in 2019, and which further developed this technology to the company's first industry-level autonomy system, which was used e.g. by the "milliAmpere2" ferry for the world's first trial operation of such a ferry in Trondheim in the autumn of 2022.

3. References to the research (indicative maximum of six references)

[1] B.-O. H. Eriksen, M. Breivik, E. F. Wilthil, A. L. Flåten and E. F. Brekke. «The Branching-Course Model Predictive Control Algorithm for Maritime Collision Avoidance», in Journal of Field Robotics, 2019. 36(7): 1222-1249. https://doi.org/10.1002/rob.21900

[2] N. P. Reddy, M. K. Zadeh, C. A. Thieme, R. Skjetne, A. J. Sørensen, S. A. Aanondsen, M. Breivik, and E. Eide. «Zero-emission autonomous ferries for urban water transport», in IEEE Electrification Magazine, Dec 2019. https://doi.org/10.1109/MELE.2019.2943954

[3] E. H. Thyri, M. Breivik and A. M. Lekkas. «A Path-Velocity Decomposition Approach to Collision Avoidance for Autonomous Passenger Ferries in Confined Waters», in Proc. 21st IFAC World Congress, Germany, 2020. https://doi.org/10.1016/j.ifacol.2020.12.1472

[4] E. F. Brekke, E. Eide, B.-O. H. Eriksen, E. F. Wilthil, M. Breivik, E. Skjellaug, Ø. K. Helgesen, A. Lekkas, A. B. Martinsen, E. H. Thyri, T. Torben, E. Veitch, O. A. Alsos, T. A. Johansen. «milliAmpere: An Autonomous Ferry Prototype», in Proc. MTEC & ICMASS, Singapore, 2022. https://doi.org/10.1088/1742-6596/2311/1/012029

[5] O. A. Alsos, E. A. Veitch, L. S. Pantelatos, K. Vasstein, E. Eide, F.-M. Petermann and M. Breivik. «NTNU Shore Control Lab: Designing Shore Control Centres in the Age of Autonomous Ships», in Proc. MTEC & ICMASS, Singapore, 2022. https://doi.org/10.1088/1742-6596/2311/1/012030

[6] Ø. K. Helgesen, E. H. Thyri, E. F. Brekke, A. Stahl and M. Breivik. «Experimental Validation of Camera-based Maritime Collision Avoidance for Autonomous Urban Passenger Ferries», in Modeling, Identification and Control, 2023. 44(2): 55-68. https://doi.org/10.4173/mic.2023.2.2

4. Details of the impact (indicative maximum 750 words)

Autonomous passenger ferries for urban waterways did not exist before NTNU's research activity which started in 2016. It took just seven years to go from an idea to a commercial product, which is quite fast in an academic environment.

The cross-disciplinary research effort involving four departments at NTNU, where ITK has played a key role by developing the unique autonomy technology required, has resulted in several important impacts:

1) The establishment of a world-leading and unique research infrastructure, today consisting of two prototype test ferries and equipment on board these, the NTNU Shore Control Lab, a digital twin (Gemini) where it is possible to test the operation of the ferries digitally and virtually, and a hybrid lab (MR-lab) which consists of both physical components and virtual reality combined, where it is possible to rapidly test the physical design of the ferries in a combined physical-virtual world. This infrastructure is continuously further developed and used for new research and innovation projects, in collaboration with partners from both the industry and public sector.

2) The competence building and graduation of over 100 MSc and BSc candidates, some now working in the spinoff company Zeabuz or other relevant maritime industry companies.

3) The competence building and graduation of over 20 PhD candidates, some now working in the spinoff company Zeabuz or other relevant maritime industry companies.

4) The competence building and graduation of 2 postdoctoral candidates, both now working in the spinoff company Zeabuz.

5) The spinoff company Zeabuz, established in 2019, currently employing 28 people and developing world-leading autonomy solutions for the maritime market in general, and autonomous passenger ferries for urban waterways in particular. The company recently won two significant awards at the prestigious "European Startup Prize" award ceremony in 2023, namely "The Urban Mobility Prize" by EIT Urban Mobility and the "River Mobility Prize" by VNF (Voies Navigables de France).

6) The world's first trial operation with an autonomous passenger ferry for urban waterways in the Canal in Trondheim during three weeks in September-October 2022. Over 1500 people, spanning from an 8 month young baby to a 96-year old adult, were successfully transported over the Canal during this period. This ground-breaking event was disseminated in over 50 newspaper and magazine articles both nationally and internationally, as well as multiple scientific publications. New research projects building on the experiences leading up to and including this trial operation have been acquired and are starting up new research these days.

7) The world's first commercial autonomous passenger ferry for urban waterways, which was contracted by the Norwegian transportation company Torghatten in the autumn of 2022, and put into use in Stockholm, Sweden since June 2023.

The European Commission anticipates in their "Sustainable & Smart Mobility Strategy" (2020) that transport by inland waterways and short sea shipping will increase by 25% by 2030. Autonomous ferries can become an important component for implementing sustainable waterborne mobility.

Specifically, these types of autonomous and urban passenger ferries can be used to replace expensive, space-consuming and not very environmentally-friendly bridge and tunnel solutions, and has the potential to revolutionize public transport in urban areas. The potential for such ferries are in the number of several thousand around the world. The core autonomy technology can also be used to install autonomous navigation solutions on board larger car ferries operating along e.g. the Norwegian coast, where it is currently hard to find qualified crew to operate such ferries. The technology can thus in time be further developed and used to enable continued coastal ferry transport for countries around the world, thus enabling a population living along the coast to have access to an important transport solution.

5. Sources to corroborate the impact (indicative maximum of ten references)

National and international media in English:

[1] 2018: https://norwegianscitechnews.com/2018/06/driverless-ferries-to-replace-footbridges/

[2] 2022: https://norwegianscitechnews.com/2022/09/ntnu-trials-worlds-first-urban-autonomous-passenger-ferry/

[3] 2022: https://youtu.be/wVMWbMSlaXM

[4] 2022: https://www.standard.co.uk/news/tech/self-driving-ferries-thames-transport-b1029135.html

National media in Norwegian:

[5] 2019: https://www.tu.no/artikler/zeabuz-tar-selvkjorende-mini-ferger-ett-skritt-naermere-markedet/481840

[6] 2022: https://gemini.no/2022/09/selvkjorende-ntnu-ferge-starter-verdens-forste-provedrift/

[7] 2022: https://www.adressa.no/nyheter/i/Xb6oOb/her-proevekjoeres-verdens-foerste-selvkjoerende-ferge-i-trondheim

[8]: 2022: https://www.tu.no/artikler/full-tillit-til-autonom-ferge/523024?key=jsYABN6r

People to contact:

[9] Erik Dyrkoren, CEO Zeabuz, e-mail: erik.dyrkoren@zeabuz.com

[10] Jan-Egil Wagnild, CTO Torghatten, e-mail: jan-egil.wagnild@torghatten.no

NTNU Department of Engineering Cybernetics – impact case 2

Institution: Norwegian University of Science and Technology (NTNU)
Administrative unit: Department of Engineering Cybernetics (ITK)
Title of case study: Improved system training for myoelectric upper limb prosthesis control
Period when the underpinning research was undertaken: 2009–2012
Period when staff involved in the underpinning research were employed by the submitting institution: 2007–date
Period when the impact occurred: 2012–date

1. Summary of the impact (indicative maximum 100 words)

Prior to this research, there was a drive towards applying pattern recognition/machine learning for myoelectric control of upper limb prostheses. However, while such control systems were working fine in labs, they appeared to be less reliable when the users brought their prosthesis home and tried to use it in everyday life.

In a research collaboration with a Canadian university that started around 2010, we discovered one important reason for this problem (what we called the "limb position effect") and suggested a solution (to train the control system with the limb in multiple positions). During the next few years, these findings affected how myoelectric prostheses are typically trained/adjusted to each prosthesis user in the clinic. Since 2020, systems with advanced pattern recognition based myoelectric control advise their users to train/calibrate their system in a variety of limb positions and re-train in specific situations where the prosthesis does not work as expected.

This technology makes controlling a powered arm or hand prosthesis significantly more reliable, personalized, and intuitive, thus helping users take maximal advantage of their modern bionic limbs.

World Health Organization (WHO) provides a global estimate of 35–40 million people who require prosthetics and orthotics services (https://www.who.int/publications/i/item/9789241512480). We are not aware of any recent studies showing how large part of this market is upper limb prosthesis users and myoelectric control.

2. Underpinning research (indicative maximum 500 words)

During this research, lasting from late Fall 2009 to about December 2011, Anders Lyngvi Fougner was a PhD student and Øyvind Stavdahl was his main supervisor and an Associate Professor, both at the Department of Engineering Cybernetics at the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway.

During the first part of this research (until June 2010), Anders Fougner was a visiting PhD student at the Institute of Biomedical Engineering at the University of New Brunswick (UNB) in Fredericton NB, Canada. This is where he discovered the "limb position effect" and initiated the following study, strongly supported by his supervisor Stavdahl, which resulted in several scientific conference papers and presentations [C],[D],[E], in one frequently cited scientific journal paper [B] and a PhD dissertation [A].

Two researchers at IBME/UNB were involved in this study. Professor Kevin Englehart and his PhD student Erik Scheme had developed a pattern recognition system that they were applying and testing in amputees, when Anders Fougner visited their lab and noticed that one amputee was struggling to control the system after moving his arm to a new position. In the following study of the limb position effect, initiated by Fougner and supported by his supervisor Stavdahl, Englehart and Scheme's pattern recognition system was used. Fougner built some of the equipment and did the data collection. One key finding in this study was that the variations in limb position associated with normal use of an upper limb prosthesis can have a substantial impact on the robustness of electromyography (EMG) based pattern recognition. The system was trained and tested in a variety of limb positions, and it was demonstrated that training in at least two positions was crucial to ensure that the system works in a larger variety of limb positions. Also, two accelerometers were applied to the upper arm and the forearm to measure the limb orientation, and it was shown that exploiting these measurements could further increase the reliability of the pattern recognition system.

Associate Professor Adrian D. C. Chan at the Department of Systems and Computer Engineering, Carleton University (Ottawa, ON, Canada) was visiting UNB during the start of this research and was involved in some of the planning and the scientific discussions during this study.

Data was recorded by Fougner during late Fall 2009 and early Winter 2010. Some initial findings were reported in a conference paper at the IEEE EMBC 2010 by E. Scheme, demonstrating the limb position effect and its importance [C].
The main (journal) paper was reported by A. Fougner in IEEE TNSRE in 2011 [B] and in a PhD dissertation in April 2013 [A], providing two solutions for how to mitigate or resolve the limb position effect.
Some follow-up research was reported in three conferences, EMBC 2011 [D], MEC 2011 [E] and TIPS 2012 [F]. Among these four publications, the TNSRE journal paper had the largest scientific impact through 389 citations to date (Nov 2023), which is significant in this field of study.

3. References to the research (indicative maximum of six references)

[A] **Fougner, A.**, *Robust, Coordinated and Proportional Myoelectric Control of Upper-Limb Prostheses*, ISBN 978-82-471-4293-6, in: Doctoral theses at NTNU (ISSN 1503-8181), 2013:98, Norwegian University of Science and Technology (NTNU), Trondheim, Norway, Apr 2013.
Publicly available in NTNU Open: http://hdl.handle.net/11250/260782

[B] **Fougner, A.**, Scheme, E., Chan, A. D. C., Englehart, K., and **Stavdahl, Ø.**, *Resolving the Limb Position Effect in Myoelectric Pattern Recognition*, IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol.19, no.6, pp. 644–651, Dec 2011. DOI: 10.1109/TNSRE.2011.2163529
Publicly available through NTNU Open: http://hdl.handle.net/11250/2392260

[C] Scheme, E., **Fougner, A.**, **Stavdahl, Ø.**, Chan, A. D. C., and Englehart, K., *Examining the adverse effects of limb position on pattern recognition based myoelectric control.* In: Conference Proceedings of the 32nd Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC 2010), Buenos Aires, Argentina, Aug 2010. DOI: 10.1109/IEMBS.2010.5627638
Publicly available through NTNU Open: http://hdl.handle.net/11250/2392881

[D] **Fougner, A.**, Scheme, E., Chan, A. D. C., Englehart, K., and **Stavdahl, Ø.**, *A Multi-Modal Approach for Hand Motion Classification Using Surface EMG and Accelerometers.* In: Conference Proceedings of

the 33rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC 2011), Boston, MA, USA, Sep 2011. DOI: 10.1109/IEMBS.2011.6091054
Publicly available through NTNU Open: http://hdl.handle.net/11250/2392221

[E] **Fougner, A.**, Scheme, E., Chan, A. D. C., Englehart, K., and **Stavdahl, Ø.**, Resolving the Limb Position Effect. In: Conference Proceedings of the MyoElectric Controls Symposium (MEC 2011), Fredericton, NB, Canada, Aug 2011. Publicly available: http://dukespace.lib.duke.edu/dspace/bitstream/handle/10161/4730/8%20Fougner.pdf

[F] **Fougner, A., Stavdahl, Ø.**, Kyberd, P. J., Losier, Y. G., and Parker, P. A., *Terminology for Control of Upper Limb Prostheses*, oral presentation at Trent International Prosthetic Symposium (TIPS 2012), May 2012. Publicly available abstract: https://folk.ntnu.no/anderfo/pro/files/TIPS 2012 Abstract - Anders Fougner.pdf

4. Details of the impact (indicative maximum 750 words)

The findings of the limb position effect were published in several scientific publications, but also in conferences/meetings where the prosthesis manufacturers participate. For example, at the "Myoelectric Controls Symposium" (MEC) in August 2011, the "IEEE Engineering in Medicine and Biology Conference" (EMBC) in August 2010 and August 2011, and at the "Trent International Prosthetic Symposium" (TIPS) in May 2012 (see references above).

Simultaneously the findings were disseminated in media like the O&P Edge (the industry's leading and most-read publication among orthotics and prosthetics professionals), Teknisk Ukeblad (a Norwegian engineering magazine), and Gemini (research news from NTNU and Sintef). Most of this happened in 2011 and 2012.

As described in pt. 2 (Underpinning research), the research was led by Anders Fougner and Øyvind Stavdahl but happened in collaboration with University of New Brunswick and Carleton University (both in Canada).

Coapt LLC (coaptengineering.com) was a pioneer and the first to introduce prosthesis control systems based on pattern recognition to the commercial market. In a support letter from December 2023, their CEO, Blair Lock, confirms that the "position effect" is taken into account, and that the techniques we introduced (improved system training in multiple limb positions) are now incorporated into clinical education practices in several countries [3].

Otto Bock SE & Co. KGaA (Duderstadt, Germany) is considered the world market leader in the field of prosthetics, including prosthetic arms and hands.

In January 2020, they launched their first pattern recognition based control system for myoelectric hands and wrists. This system is called MyoPlus. The user guide for training of this system is published at [1] and mentions several times (e.g. at page 26, 27 and 30) that the system needs to be trained in multiple arm positions, much like we proposed in our research some years earlier.

During the first part of system training, they suggest 3 different limb positions ("*with elbow flexed at 90 degrees*", "*with the arm hanging down*", and "*with the arm extended*") and thereafter they suggest making additional recordings "*when a movement is not adequately recognized in certain situations or arm positions, such as when the hand is above the head*".

It is also briefly visible in their video of how to adapt the system to the user [2].

5. Sources to corroborate the impact (indicative maximum of ten references)

[1] Otto Bock SE & Co. KGaA (Duderstadt, Germany): Myo Plus Pattern Recognition – Update Reference Guide. To be found also at the "Resource Center" at their web page for the product MyoPlus.

[2] Otto Bock SE & Co. KGaA (Duderstadt, Germany): Video of how to adapt their MyoPlus pattern recognition system to the user. Otto Bock SE & Co. Available on YouTube: https://youtu.be/OhvYYnTKVRA?t=462s

[3] Statement/support letter by Blair Lock, CEO of Coapt LLC, Dec 2023. *Document attached*.

December 7, 2023

Øyvind Stavdahl, PhD
Professor, Medical Cybernetics
Department of Engineering Cybernetics
Norwegian University of Science and Technology (NTNU)
Trondheim, Norway

To whom it may concern,

Our company, Coapt (coaptengineering.com) was the pioneer and the first to introduce upper limb prosthesis control systems based on pattern recognition to the commercial market. Today, Coapt is the clear commercial leader in this niche space and more than 1000 users have been fitted with the Coapt system worldwide. This technology makes controlling a powered arm or hand prosthesis significantly more reliable, personalized, and intuitive, thus helping users take maximal advantage of their modern bionic limbs.

User needs and characteristics vary significantly, and therefore numerous tactics are used to optimize the prosthesis control. One of the tactics we encourage our users and their clinical teams is to consider while personalizing (calibrating) their control system is to hold and/or move the limb in several different functional positions. In this manner, myoelectric signals corresponding to varied limb position (a phenomenon referred to as the “position effect”), add to the robustness for functional control.

The existence of the position effect and the importance of accounting for it during system training was first explored in a research collaboration between the Institute of Biomedical Engineering at the University of New Brunswick, Canada, and the Department of Engineering Cybernetics at the Norwegian University of Science and Technology, Norway. The initial publications by Anders Fougner, Eric Scheme et al. approximately one decade ago paved the way for numerous subsequent studies. The resulting techniques are among several important innovations that facilitated the clinical introduction of modern myoelectric control systems. Accordingly, these techniques are now incorporated into clinical education practices in several countries.

Sincerely,

Blair Lock

BLAIR LOCK
CEO

NTNU Department of Engineering Cybernetics – impact case 3

Institution: Norwegian University of Science and Technology (NTNU)
Administrative unit: Department of Cybernetics Engineering (ITK)
Title of case study: Unlocking the potential of UAV operations in icing conditions
Period when the underpinning research was undertaken: 2014- today
Period when staff involved in the underpinning research were employed by the submitting institution: 2014-today
Period when the impact occurred: 2022-onwards

1. Summary of the impact (indicative maximum 100 words)
This section should briefly state what specific impact is being described in the case study.

This technology unlocks the potential of UAVs and drones to operate safely in cold weather conditions – thus unlocking substantial public, commercial, and defense applications.

Uncrewed Aerial Vehicles (UAVs) are an emerging technology with a wide range of applications including public services, commercial markets, and defence. In-flight icing on UAVs is a severe safety hazard and operational limitation in cold weather, as often encountered in Norway and globally. Our research lab has spearheaded the field and is today internationally leading it. Based on our results, spun-off a company commercializing ice protections systems for UAVs in 2017, UBIQ Aerospace (30+ employees). Our research unlocks the use of UAVs for applications e.g. medical logistic services, search&rescue, and defense. Furthermore, our innovative technologies contribute to the green transition in aviation, e.g. for fully-electric aircraft or eVTOLs. The EU projected that the drone service market in Europe could be worth €14.5 billion, and create 145,000 jobs, by 2030.

2. Underpinning research (indicative maximum 500 words)

Atmospheric in-flight icing occurs whenever a UAV or aircraft encounters supercooled liquid droplets inside clouds or freezing precipitation (rain/drizzle). These droplets have a temperature below the freezing point but are in liquid. When these supercooled liquid droplets impact on a surface they freeze and quickly accumulate into ice shapes. These ice accumulations alter the aerodynamic shape of critical surfaces such as wings and propellers, leading to substantial aerodynamic performance losses (e.g. 80% efficiency loss on a rotor within 120s of moderate icing). Icing is a severe hazard for UAVs and can quickly lead to loss of the aircraft without suitable protection systems – as a result UAVs are typically not operated beyond visual line of sight when there is cold temperatures and visible moisture in the air (e.g. clouds, fog). Icing can occur worldwide and at any time of the year, but is especially prevalent in colder climates and higher latitudes. While in-flight icing is a mature research field in manned aviation, little research has been conducted on the topic before 2014. Due to the big differences in configuration, size, airspeed, and operational environment solutions and methods developed for manned aviation are not easily transferred to u

Our research journey began in 2014 with PhD candidate Kim Sørensen, under the guidance of Prof. Tor Arne Johansen, during a research exchange at NASA Ames Research Center. It was here that Kim first encountered the critical issue of in-flight icing on UAVs, a problem notably affecting the US Coast Guard's operations. This discovery unveiled a significant research gap in UAV icing and its implications for various UAV applications, including search and rescue, package transport, and defense.

Motivated by these findings, Kim Sørensen embarked on developing an autonomous ice protection system for UAVs in his PhD project [1]. This venture that received further support through RCN funding. In 2016, Kasper Borup, with his expertise in air data estimation for UAVs, joined the team to propel the commercialization of this innovative system. This collaboration led to the establishment of UBIQ Aerospace in 2017 with the NTNU Technology Transfer Office (NTNU TTO). UBIQ Aerospace is a spin-off company from NTNU IKT dedicated to the development and commercialization of comprehensive ice protection systems for UAVs. Today the company has since grown into a leading supplier in this domain with more than 30 employees, with customers like Boeing Insitu and Lockheed Martin.

At NTNU ITK, Richard Hann continued advancing the research on UAV icing challenges during his PhD project [2]. Under the joint supervision of Hann and Prof. Johansen, the NTNU UAV Icing Lab was established in 2020, following successful RCN fund applications. The Lab, now steered by Hann, is at the forefront of UAV icing research, supported by five PhD candidates and numerous Master's students exploring various related topics since 2021.

One of the Lab's significant achievements, in synergy with other researchers at ITK, is the development of a sophisticated path-planning toolbox [4]. By enabling flight planning in areas prone to icing, this innovation greatly reduces the risk of UAV icing. In the arena of simulation and modelling, the Lab is at the forefront of applying state-of-the-art icing computational fluid dynamic (CFD) tools for icing simulation. We published a handbook chapter on the topic, that sets the benchmark for icing CFD simulations on UAVs [5]. In addition, the lab is developing algorithms for sensor-free ice detection by monitoring performance.

Lastly, the ongoing collaboration between the Lab and UBIQ has resulted in the development of an innovative ice protection system for UAV propellers [6]. This system is a critical milestone in ensuring the reliability and safety of UAV operations under icing conditions. Its efficiency and effectiveness in protecting UAV propellers from ice accumulation enhances operational safety and also opens new possibilities for UAV applications.

Today, the UAV Icing Lab's research excellence is globally acknowledged, showcased by collaborations with prestigious institutions like NASA Glenn Icing Branch, German Aerospace Center (DLR), the von Karman Institute (VKI), or the Technical Research Centre of Finland (VTT). In addition the Lab is leading key research activities in the field, for example by organising the 1st International UAV Icing Workshop in 2022 and leading the NATO RTO AVT-399 Research Task on UAV icing.

Key researchers:

- Dr. Kim Lynge Sørensen, PhD candidate 2013-2016,Post-doc 2016-2018, Now CEO at UBIQ Aerospace
- Dr. Kasper Trolle Borup, PhD candidate 2014-2018, Innovation Post-doc 2018-2019, Now CTO at UBIQ Aerospace.
- Dr. Richard Hann, PhD candidate 2016-2020, Post-doc 2020-2021, Senior Researcher 2021-today, Now Director of the UAV Icing Lab
- Prof. Tor Arne Johansen, Professor at ITK throughout the entire period, Co-directing the UAV Icing Lab
- Nicolas Müller, PhD candidate 2021-2024, Industrial PhD with UBIQ
- Joachim Wallisch, PhD candidate 2021-2025, Funded by IPN project with UBIQ
- Michael Cheung, PhD candidate 2021-2025, Funded by IPN project with UBIQ
- Bogdan Løw-Hansen, PhD candidate 2021-2025, Funded by IKTPLUSS project
- Markus Lindner, PhD candidate 2022-2025, Funded by IKTPLUSS project

3. References to the research (indicative maximum of six references)

[1] Sørensen, Kim Lynge. (2016). "Autonomous Icing Protection Solution for Small Unmanned Aircraft: An Icing Detection, Anti-Icing and De-Icing Solution". Doctoral thesis at NTNU;2016:275. http://hdl.handle.net/11250/2417471

[2] Hann, Richard (2020). "Atmospheric Ice Accretions, Aerodynamic Icing Penalties, and Ice Protection Systems on Unmanned Aerial Vehicles". Doctoral thesis at NTNU;2020:200. https://hdl.handle.net/11250/2657638

[3] Hann, R., Johansen, T.A. (2020). "Unsettled Topics in Unmanned Aerial Vehicle Icing". SAE International, SAE EDGE Research Report EPR2020008. https://doi.org/10.4271/EPR2020008 (available upon request to richard.hann@ntnu.no)

[4] Hovenburg, A. R., Andrade, F. A. A., Hann, R., Rodin, C. D., and Johansen, T. A., Storvold, R. (2020). Long Range Path Planning Using an Aircraft Performance Model for Battery Powered sUAS Equipped with Icing Protection System. IEEE Journal on Miniaturization for Air and Space Systems. https://doi.org/10.1109/JMASS.2020.3003833

[5] Hann, R. (2023). "Numerical Simulation of In-Flight Icing of Unmanned Aerial Vehicles". In: Habashi, W.G. (eds) Handbook of Numerical Simulation of In-Flight Icing. Springer. https://doi.org/10.1007/978-3-030-64725-4_12-1

[6] Müller, N.C., Løw-Hansen, B., Borup, K.T., Hann, R. (2023). "UAV icing: Development of an ice protection system for the propeller of a small UAV. Cold Regions Science and Technology", 213, 103938. https://doi.org/ 10.1016/j.coldregions.2023.103938

4. Details of the impact (indicative maximum 750 words)

This section should provide a narrative, with supporting evidence, to explain:

- How the research underpinned (made a distinct and material contribution to) the impact
- The nature and extent of the impact

The following should be provided:

Highlighting the research gaps between manned and unmanned aviation

Our initial research in 2014-2017 set a baseline for future exploration by pinpointing the specific challenges UAVs face with in-flight icing – a hazard that was not clearly understood in the unmanned sector. This not only directed future research questions but also raised awareness among users, operators, and manufacturers about the critical need to address icing risks in UAV design and operation. This also highlighted potential synergies to other research field such as icing on wind turbines.

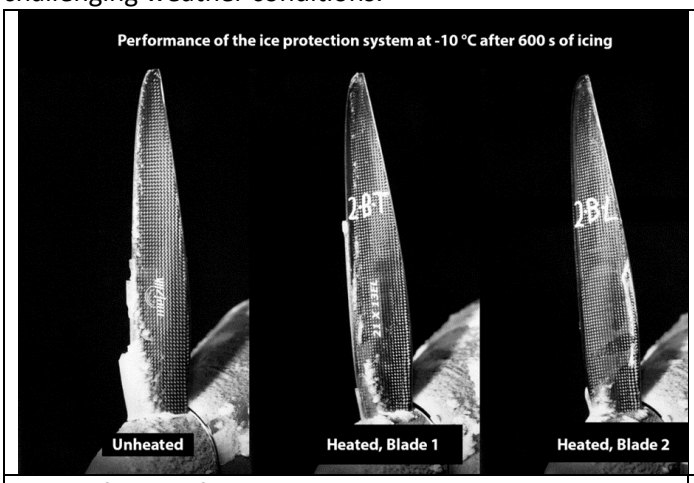
Spin-off company

Based on research at NTNU ITK, the spin-off company UBIQ Aerospace was funded in 2017. Initially, with only 3 employees, the company has developed into one of the most successful deep-tech startup companies in Norway. Today, the company employs more than 30 people and is aiming to grow continuously in the future. In addition to RCN funding, UBIQ received several million Euro in private equity investments from several companies: 6AM, Lupa Systems, and Statkraft Ventures. The obtainable market is estimated based on production capability in the first 5 years of sales and the average selling price. In the commercial sector by 2030 UBIQ estimate sales of 23 thousand units in a year at an average price of €13k making the Serviceable obtainable market of €288M.

Development of ice protection and detection systems

Our research in developing ice protection systems has led to significant advancements and applications in the field of UAV technology. Building on our initial research, a spin-off company UBIQ was established in 2017, focusing on the practical application of our findings. Together, we developed an innovative ice protection system based on electrothermal heating, designed to safeguard both wings and propellers of UAVs. This system was put to the test in a collaborative research project with the Norwegian Defence Research Establishment (FFI) and Maritime Robotics, a leading Norwegian UAV manufacturer. The project's highlight was the successful flight of an ice-protected UAV under actual icing conditions, demonstrating the effectiveness of our system in real-world scenarios in 2022.

The impact of our work extends to the Norwegian defence forces, which will utilize our findings and results. Notably, the next tender for tactical UAVs issued by the Norwegian defence will include specific requirements for icing conditions, a direct consequence of our research and its practical implications. Moreover, our research has opened doors to collaborations with emerging sectors like air taxis (eVTOL) and green aviation aircraft companies. The synergy between our ice protection technology and the needs of these innovative aviation sectors is clear, and our collaboration aims to further enhance the safety and efficiency of these next-generation aircraft in challenging weather conditions.



Successful test of a propeller ice protection. No ice accumulates on blade 2 after 10min of moderate icing.

Successful flight test with UBIQ Aerospace, FFI, and Maritime Robotics

Development and validation of icing CFD tools

The development and validation of icing Computational Fluid Dynamics (CFD) tools represent a significant stride in our research endeavors. Our collaboration with ANSYS, a leader in engineering simulation software, has been pivotal. As a core user of their icing CFD code, FENSAP-ICE, we have been jointly developing models that are crucial for understanding and mitigating icing risks on UAVs. A key achievement in this collaboration has been establishing the first validation cases suitable for UAVs, derived from icing wind tunnel experiments. These cases have been integral to our work and were featured in the 2nd Ice Protection Workshop, an international forum dedicated to benchmarking icing CFD codes. Our involvement in this workshop underscores our role in leading the conversation on icing simulation in the UAV sector. We have been at the forefront of applying 3D icing simulations on propellers and rotors, a complex yet crucial area for UAV operation safety. The outcome of this collaboration and research is significant: we are establishing CFD methods as a standard practice for assessing icing risks and designing ice protection systems for UAVs. These methods are now recognized as a key component in creating efficient and reliable ice protection systems. The baseline our know-how was published in a chapter in an handbook

and we have feedback that these methods are being used today by several users, e.g. at von Karman Institute, Iowa State University, NASA, UBIQ Aerospace, and others. Our advancement marks a substantial contribution to enhancing the safety and operational capabilities of UAVs in challenging environments.

Societal impact

Our research to unlock the potential of drones for cold weather operations has the potential to accelerate technological developments in countless segments across the globe. In particular, two applications will be highlighted, where we already have contributed to the impact. First, impact on health services mainly through: speeding up the transportation of essential medical supplies, transportation of blood and organs to remote locations, transportation of the blood or specimen samples to the specialised labs, transportation of essential life-saving medicines in cases of emergency. The UAV Icing Lab is in discussions with large drone health-care companies such as Zipline and Matternet. In addition, the Lab contributed to a study with Oslo Universitetssykehus and FFI (https://www.ffi.no/publikasjoner/arkiv/icing-and-wind-implications-and-mitigations-in-high-intensity-safety-critical-drone-operations-in-norway). Second, the Lab has contributed unlocking cold weather operations for military and defense application, for example for surveyance in adverse weather conditions or in cold climate regions. Here, we are working with the Norwegian Defence Research Establishment (FFI), UBIQ Aerospace, and Maritime Robotics and have developed a prototype UAV that has a full ice protection system which has been successfully tested in Autum 2022. This is a key milestone to unlocking further application of defense drone applications.

5. Sources to corroborate the impact (indicative maximum of ten references)

Invited lecture on UAV icing by NASA Advanced Supercomputing (NAS) Division (2020). Link

Article about synergies between icing on wind turbines and drones in WindTech (2019). Link

Article on UAV Icing by Pointwise/Neptech, one of largest suppliers of CFD meshing software (2020). Link

Package delivery to your door by drone now one step closer in Norwegian SciTech News (2021). Link

https://www.prnewswire.com/news-releases/ubiq-aerospace-and-insitu-join-forces-to-winterize-the-integrator-uas-301411325.html

https://techxplore.com/news/2021-12-enable-drones-de-ice-wings-automatically.html

https://spectrum.ieee.org/ubiq-aerospace-brings-the-first-drone-deicing-system-to-market

https://www.suasnews.com/2023/05/the-worlds-first-ice-protection-solution-for-uas-approved-by-the-norwegian-ministry-of-defense/

Video Testing ice protection systems for UAVs https://www.youtube.com/watch?v=K5QGIyBHKKo

Video Wind tunnel experiments on UAV icing https://www.youtube.com/watch?v=jZfjtbI7mcs

IES 1

Institution: Norwegian University of Science and Technology (NTNU)
Administrative unit: Department of Electronic Systems (IES)
Title of case study: Epitaxial III-V nanowires on graphene for UV-disinfection
Period when the underpinning research was undertaken: 2005 – 2022, with weight on 2015-2022 for UVC sources
Period when staff involved in the underpinning research were employed by the submitting institution: 2005 - 2022
Period when the impact occurred: 2012 - 2022

Summary of the impact (indicative maximum 100 words)

New technology platform based on epitaxial III-V semiconductor nanowires on graphene. The platform allows to combine the electro-optical properties of III-V semiconductor systems with the electrical, optical- and mechanical properties of graphene. This encompass ultraviolet-C (UVC) light sources with incredible ability to kill 99.9% of bacteria and viruses in seconds at a wavelength near 265 nm, which creates sufficient energy to neutralize pathogens by disrupting their DNA. UVC light as a disinfection method is being increasingly applied to mainstream solutions, such as food package, surface, air and water disinfection. Based on the research a spin-off company, CrayoNano AS, was established, and in 2022 CrayoNano released their first commercial UVC Light Emitting Diode (LED) product for water disinfection on the market under the brand name CrayoLED™.

1. Underpinning research (indicative maximum 500 words)

Prof. Weman and Prof. Fimland initiated basic research work on III-V semiconductor nanowires for optoelectronic device applications at NTNU in 2005. In March 2010 they discovered how semiconductor nanowires can be epitaxially synthesized on graphene.

To support this research the IE faculty at NTNU decided to co-finance a III-nitride MBE system and a UVC laser upgrade in order to aid in deep UV nanomaterials research in the group Prof. Weman and Prof. Fimland. The new III-nitride MBE system was inaugurated by the dean at IE in 2015 and subsequently led to the first nanowire/graphene UV LED published by NTNU in 2019.

Also, an important aspect of this endeavor has been a collaboration between NTNU and the spin-off company CrayoNano, with the oversight and help from TTO to ensure that legal aspects are correct. This has enabled large externally funded activity, and CrayoNano and NTNU have been co-applicants on several projects funded by RCN (NANO2021, ENERGIX, IPN), Nordic Innovation (NANORDSUN) and EU (NAGRALED and an EIC Accelerator grant to CrayoNano in 2021). CrayoNano and NTNU have co-advised on the master thesis of several NTNU students.

The above research and spin-off company would not have been possible without the excellent laboratory facilities for nanomaterials research at NTNU including the:

- NTNU NanoLab clean room established in 2009.
- III-V semiconductor MBE lab established at IES in 1988.

– And access to Advanced characterization labs (e.g. TEM Gemini Centre, nanophotonics lab.)

- Helge Weman (Professor at IES) and Bjørn Ove Fimland (Professor at IES) initiated the research
- Helge Weman (Professor at IES), Bjørn Ove Fimland (Professor at IES) and Dong Chul (postdoc at IES) founded CrayoNano

3. References to the research (indicative maximum of six references)

1.
Authors: Ida Marie Høiaas, Andreas Liudi Mulyo, Per Erik Vullum, Dong-Chul Kim, Lyubomir Ahtapodov, Bjørn-Ove Fimland, Katsumi Kishino, Helge Weman
Title: GaN/AlGaN nanocolumn ultraviolet light-emitting diode using double-layer graphene as substrate and transparent electrode

Year of publication: 2019
Journal: Nano letters 19 (3), 1649-1658 (2019)
URL: https://pubs.acs.org/doi/10.1021/acs.nanolett.8b04607

2.
Authors: Dingding Ren, Lyubomir Ahtapodov, Julie S Nilsen, Jianfeng Yang, Anders Gustafsson, Junghwan Huh, Gavin J Conibeer, Antonius TJ Van Helvoort, Bjørn-Ove Fimland, Helge Weman
Title: Single-mode near-infrared lasing in GaAsSb based nanowire superlattice at room temperature

Year of publication: 2018
Journal: Nano letters 18 (4), 2304-2310 (2018)
URL: https://pubs.acs.org/doi/10.1021/acs.nanolett.7b05015

3.
Authors: Abdul Mazid Munshi, Dasa L Dheeraj, Vidar Tonaas Fauske, Dong-Chul Kim, Junghwan Huh, Johannes F Reinertsen, Lyubomir Ahtapodov, KD Lee, Babak Heidari, ATJ Van Helvoort, Bjørn-Ove Fimland, Helge Weman
Title: Position-controlled uniform GaAs nanowires on silicon using nanoimprint lithography

Year: 2014
Journal: Nano letters 14 (2), 960-966, 2014
URL: https://pubs.acs.org/doi/10.1021/nl404376m

4.
Authors: A Mazid Munshi, Dasa L Dheeraj, Vidar T Fauske, Dong-Chul Kim, Antonius TJ van Helvoort, Bjørn-Ove Fimland, Helge Weman
Title: Vertically aligned GaAs nanowires on graphite and few-layer graphene: generic model and epitaxial growth

Year: 2012
Journal: Nano letters 12 (9), 4570-4576, 2012
URL: https://pubs.acs.org/doi/abs/10.1021/nl3018115

5.

Authors: Lyubomir Ahtapodov, Jelena Todorovic, Phillip Olk, Terje Mjåland, Patrick Slåttnes, Dasa L Dheeraj, Antonius TJ van Helvoort, Bjørn-Ove Fimland, Helge Weman
Title: A story told by a single nanowire: optics properties of wurtzite GaAs

Year: 2012
Journal: Nano letters 12 (12), 6090-6095, 2012
URL: https://pubs.acs.org/doi/10.1021/nl3025714

6.
Authors: Thang Ba Hoang, Anthonysamy F Moses, Lyubomir Ahtapodov, Hailong Zhou, Dasa L Dheeraj, Antonius TJ Van Helvoort, Bjørn-Ove Fimland, Helge Weman

Title: Engineering parallel and perpendicular polarized photoluminescence from a single semiconducting nanowire by crystal phase control

Year: 2010
Journal: Nano letters 10 (10), 2927-2933, 2010
URL: https://pubs.acs.org/doi/abs/10.1021/nl101087e

4. Details of the impact (indicative maximum 750 words)

Based on the discovery in March 2010 how semiconductor nanowires can be grown on graphene NTNU Technology Transfer office (TTO) was contacted in order to see if it would be beneficial to commercialize this idea. TTO helped with the initial patent filings (first patent submitted in Dec. 2010), seed corn funding and initiated a business plan. First seed corn fundings came from the NTNU Discovery fund and RCN's FORNY program that eventually led to that CrayoNano was established in 2012 with prof. Weman, prof. Fimland and post.doc. Dong Chul as co-founders and first employees of the company.

A very successful world-wide media coverage was done in autumn of 2012 through an NTNU press release including the news of a peer-reviewed journal publication, the establishment of CrayoNano and the launch of an animated YouTube video that quickly became viral.

Followed by the initial research ideas and results on III-nitride nanowires in the group of prof. Weman and prof. Fimland at NTNU, CrayoNano decided in 2015 to work on the development of nanowire/graphene-based UVC LEDs for disinfection applications as a first commercial product. In 2022 CrayoNano released their first commercial UVC LED product for water disinfection on the market under the brand name CrayoLED™.

Today CrayoNano has HQ in Trondheim, Norway and a branch office in Taiwan with a total of 35 employees. CrayoNano is a fab-lite semiconductor company. It has an extensive IP portfolio based on its innovative nanomaterials-based technology positively impacting semiconductor manufacturing - initially applied to disrupt performance for UVC LEDs in several new applications across water, air and surface disinfection. The research at NTNU has resulted in 15 patent families, with 115 granted patents and 50 pending patents.

15 patent families (with 115 granted patents and 50 pending patents):

1. H. Weman et al., "Growing nanowires on graphene", priority date 131210. Granted in 23 countries.

2. H. Weman et al., “Graphene top contact to metal catalyst nanowires”, priority date 100112. Granted in 9 countries.

3. H. Weman et al., “Multijunction graphene solar cell”, priority date 210612. Granted in 9 countries.

4. B.O. Fimland et al., “Thin film semiconductors on graphene”, priority date 210613. Granted in 11 and pending in 1 country.

5. C.G. Lim and H. Weman, “Optimizing nanowire solar cell”, priority date 140813. Granted in 7 countries.

6. D.C. Kim et al., “Hole mask layer on graphene”, priority date 130715. Granted in 19 and pending in 2 countries.

7. D.L. Dheeraj et al., “Flip-chip nanowire/graphene UV LED”, priority date 130715. Granted in 16 and pending in 3 countries.

8. M. Munshi et al., “Nucleation of nanowires on graphene”, priority date 310715. Granted in 5 and pending in 6 countries.

9. B.O. Fimland et al., “Nanowire laser and RC-LED on graphene”, priority date 020317. Granted in 9 countries.

10. H. Weman et al., “Nanowire growth on GaO substrate and devices”, priority date 100417. Granted in 6 and pending in 2 countries.

11. M. Munshi et al., “h-BN nanowires for devices”, priority date 100918. Granted in 1 and pending in 4 countries.

12. M. Munshi et al., “Hole in graphene mask”, priority date 160719. Pending in 8 countries.

13. M. Munshi et al., “Remote epitaxy of nanowires on graphene”, priority date 230919. Pending in 8 countries.

14. NOT YET DISCLOSED, priority date 250822. Pending in 8 countries.

15. NOT YET DISCLOSED, priority date 250822. Pending in 8 countries.

5. Sources to corroborate the impact (indicative maximum of ten references)

- Eivind Andersen, managing director NTNU TTO, phone: +47 900 30 570, e-mail: eivind.andersen@ntnu.no
- Jo Uthus, chairman of the board of CrayoNano, phone: +47 47380634, e-mail: jo.uthus@crayonano.com

IES 2

Institution: Norwegian University of Science and Technology (NTNU)
Administrative unit: Department of Electronic Systems (IES)
Title of case study: Home of the trolls/"Troll i ord"
Period when the underpinning research was undertaken: 2018-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2018-2022
Period when the impact occurred:2021-2022

1. Summary of the impact (indicative maximum 100 words)

Cultural & adventure tourism often coincide at locations and geographical spaces that have legends, stories, and folklore associated with them. Norwegian folklore is full of stories about the Trolls in the spectacular Norwegian landscape. Trolls are intrinsically related to the environmental features of the landscape. We developed an application for a local tourism company interested in using this Norwegian mythical folklore to promote activities in a protected nature area. The aim of the project was to find alternatives to mountain signposts used for informing visitors. The application was designed to deliver a story-world blurring the line between reality and fiction.

2. Underpinning research (indicative maximum 500 words)

Prof. Andrew Perkis initiated basic research in Multimedia Signal Processing with his course TTT4135 Multimedia Signal Processing in 1998. The research at this stage was mainly focused on Audio visual compression, optimization of algorithms and quality modelling and assessment of the finished systems. The work was put into Q2S-Centre for Quantifiable Quality of Service in Communication Systems, a Centre of Excellence at the IE faculty (2003-2013). With the Centre the focus of research changed and focused more on multimedia experiences and Quality of Experience (QoE). The 10 years of research at Q2S strengthened the IE/IES position in this field and provided a momentum for further explorations. The next period from 2013 focused on defining, designing, implementing, and evaluating Immersive Media Experiences – IMX. The promising technologies investigated where Virtual reality and augmented Reality, later all put into the concept of eXtended Reality (XR).

"Home of the Trolls" builds on our IMX expertise and in particular looks at the use of digital media and IMX to redefine our experience of tourism services. One such example is technology-driven storytelling: a useful means of exploration, especially for those looking to expand upon their cultural, historical, and geographical awareness through meaning-making and self-learning. Advancements in information & media technology have contributed to our meaning- and sense-making abilities by introducing new delivery mechanisms, media forms, and tools. The use of geo-referenced and immersive media applications within this context has a promising future for enriching tourism/adventure experiences. In Home of the Trolls, we designed, implemented and tested there cycles of prototypes for locative or location-based media (LBM) and Augmented Reality (AR) technologies to rove the concept.

"Troll i ord" followed up on the final prototype and refined this into a complete XR system for the troll IMX and tested this on location in Rindal, Norway with the company iTrollheimen. The results were finally transferred to iTrollheimen who together with BreachVR have commercialized and sold the product to many Norwegian national parks and are currently refining and expending the troll universe for future explorations.

The research started at Sense-IT, NTNU IES multimedia laboratory. **NTNU/Sense-IT** is the main laboratory for our research within Interactive Digital Narrative, Digital Storytelling and Digital Storytelling Tools. The laboratory has infrastructure necessary for designing, implementing and

validating Interactive Digital Narratives by using XR technologies. Sense-It was established during the departments Centre of excellence – Q2S – in 2003.

The key researchers have been:

Andrew Perkis, Professor and director of Sense-IT, 1998-2022
Øyvind Klungre, Researcher, 2018-2022
Asim Hameed, PhD student, 2018-2020.

The timeline for the work is:
1998-2003 Basic research at IES/Signal processing group
2003-2013 Basic research at Q2S
2013-2018 Basic and applied research at IES/Signal processing group
2018-2019 Home of the Trolls contract with iTrollheimen (pre-project grant)
2019-2021 Troll i ord contract with iTrollheimen (qualification grant)
2021 DOFI submitted through NTNU TTO
2022 Final signing of IP rights in 2022 to iTrollheimen and BreachVR
2022 – Commercialisation and product launch by iTrollheimen

Research on Digital storytelling exploring the synergies between Art, technology and Digital Humanities has been incorporated in our proposals and successful Horizon 2020 and HEUROPE projects and COST actions: Visual media (H2020, ICT-19), AdMire (H2020, ICT-55), ULTIMATE (H2020, EASME), 5GMediaHub (H2020, ICT-41), Qualinet and INDCOR (COST action CA 18230).

3. References to the research (indicative maximum of six references)

ØS Klungre, A Hameed, T Ebrahimi, A Perkis
Validation and assessment of a mixed reality solution for enhanced TV viewer engagement
Applications of Digital Image Processing XLVI 12674, 43-51
URL

A Hameed, ØS Klungre, A Perkis, G Bolme, A Brownridge
User evaluation of a storytelling application assisting visitors in protected nature areas
Interactive Storytelling: 14th International Conference on Interactive Digital Storytelling, ICIDS 2021, Tallinn, Estonia, December 7–10, 2021, Proceedings 14
URL

A Perkis, C Timmerer, et al
QUALINET white paper on definitions of immersive media experience (IMEx)
arXiv preprint arXiv:2007.07032
URL

ØS Klungre, A Hameed, A Perkis
Narrative's impact on quality of experience in digital storytelling
SA'19: SIGGRAPH ASIA Art Gallery/Art Papers
URL

4. Details of the impact (indicative maximum 750 words)

Home of the Trolls funded by DistriktForsk – Forprosjekt 2019

The project initially started with a call from Innovation Norway's "kompetansemegler" from the Orkland region outside of Trondheim wanting to put us in contact with one of their local members, iTrollheimen, an event based company From Rindal. iTrollheimen had an idea to develop their events focusing on trolls as a living creature and telling the story of their role in preserving nature.

The troll is one of the country's most talked about mythical figures, in addition to being one of Norway's biggest trademarks in the tourism context. The mountain area Trollheimen, which is understood in English as Home of the Trolls, is, as the name suggests, the place where these figures originate. Through a collaboration between iTrollheimen AS, NTNU and NORD University, we took a closer look at how we can use trolls to convey natural values in an untraditional and innovative way to the public and over time develop Norway's only digital nature park centre. How can one convey knowledge of nature in an alluring, innovative and playful way? This project wanted to replace the traditional info signs and plaques with the trolls in Trollheimen. Based on our stories and IMX technology, guests will get to know nature through the trolls' everyday lives. Can we increase the engagement and interest of people by making trolls aware of an area's conservation and natural values?

Through the project, we have developed an extensive universe consisting of trolls with different properties and knowledge of nature. The trolls have been modelled and animated into an internal app. The prototype has been tested in the field with GPS triggers. The results were as expected, and the project has worked extremely well. We see that the trolls, together with the storytelling, really elevate the experience and raise awareness of the dissemination of nature. Creating a common thread through the experience also seems to increase the presence for the guest. These findings indicate that we are well on the way to developing a new, non-traditional way of communicating natural values outdoors.

The Home of the Trolls results were so promising that we decided to move to the stage through Regionalt Forskningsfond Trøndelag (RFF)

"Troll i ord" funded by Regionalt Forskningsfond Trøndelag (RFF)

The goal of the project is to develop a non-traditional methodology for conveying nature and cultural heritage, as well as developing digital storytelling tools, optimizing QoE in local digital storytelling, and commercialization for usage in regional destination development.

"Troll i ord" builds on Home of the Trolls and takes the previous lab results from the lab to the real world. The first stages happened indoors with motion tracking, before a prototype was made for outdoor usage. This project expands on the progress made outdoors. An augmented reality (AR) application will be made for a handheld device, using live location as input. The project achieved the following:

- A working prototype in Rindal which can be used for demonstrations and applying for funding for further development
- Expanded the storytelling tools
- Developed the story world of the trolls
- Remodelling of trolls for animation
- Animating the trolls using main body motion capture
- Conducted a formal, subjective evaluation of prototype

The work in the final stages has been a collaboration between NTNU, Nord University and iTrollheimen

NTNU: project managers and initial idea, prototype development and validation and test
NORD: 3D models of the trolls
iTrollheimen: Owner of the story, narrative development, troll concepts and music.

Through RRF, NFR and Innovation Norway NTNU and NORD have been the beneficiaries under contract by iTrollheimen.

The developed and commercialised universe of Home of the Trolls is officially launched by iTrollheimen.

https://www.homeofthetrolls.no/
https://itrollheimen.no/events/
https://www.trondelagfylke.no/nyhetsarkiv/tester-ut-nye-former-for-naturformidling/
https://www.nrk.no/mr/har-_forska_-pa-troll-i-trollheimen--no-skal-dei-bygge-eit-trollunivers-1.16013635

- Dates of when these impacts occurred.

2022- ongoing

5. Sources to corroborate the impact (indicative maximum of ten references)

Gøran Bolme, CEO iTrollheimen, phone: + 47 907 89 629, e-mail: post@itrollheimen.no

Eivind Andersen, managing director NTNU TTO, phone: +47 900 30 570, e-mail: eivind.andersen@ntnu.no

IES 3

Institution: Norwegian University of Science and Technology (NTNU)
Administrative unit: Department of Electronic Systems (IES)
Title of case study: Autonomous ferries
Period when the underpinning research was undertaken: 2016 – 2022.
Period when staff involved in the underpinning research were employed by the submitting institution: 2015 – 2022
Period when the impact occurred: 2016 - 2022

1. Summary of the impact (indicative maximum 100 words)

The development of the autonomous urban passenger ferries "milliAmpere1" and "milliAmpere2" was initiated in 2016. The first ferry "milliAmpere1" was launched in 2017 and served as a development platform for master and Phd candidates developing sensor systems, control systems and software for situational awareness and collision avoidance. The second ferry, "milliAmpere2", launched in 2020, is capable of carrying 12 passengers and was used for full-scale testing with passengers in 2022. As a direct result of this research and innovation, the spin-off company Zeabuz AS was founded in 2019.

2. Underpinning research (indicative maximum 500 words)

Associate prof. Egil Eide initiated the project of designing autonomous ferries for urban passenger transportation using waterways, rivers and canals in cities. In the time period between 2015 and 2019 there has been significant research activity within autonomy at NTNU Department of engineering cybernetics (AutoSea project). The natural choice was therefore to collaborate with NTNU Department of Engineering Cybernetics and Department of Marine Technology to build on a broad range of competence and research activity. The initiative led to the project of building the first ferry "milliAmpere1" which was launched in November 2017. The 5 meter long ferry was financed by NTNU and was used extensively by PhD candidates and master students to develop control systems, dynamic positioning systems, sensor systems and software for autonomous operation of the ferry.

In 2019 the team received financing from NTNU for building the 8 meter long ferry, "milliAmpere2", which was certified for passenger transportation with 12 passengers. NTNU department of Design became involved in the development of the new ferry and contributed with aspects like human-machine interaction and human-centered design. Parallel to this the NTNU TTO was involved in the project and secured funding from NTNU Discovery and the Research Council of Norway's FORNY program for further development of the technology. The spin-off company Zeabuz AS was established in November 2019 by researchers from Department of Electronic Systems and Department of Engineering Cybernetics Systems to commercialize the technology.

After a testing and verification period from 2020 – 2022, "milliAmpere2" conducted the world's first trial operation of an autonomous passenger ferry in September 2022. In June 2023 the first commercial autonomous ferry "Estelle" entered regular traffic in Stockholm using Zeabuz autonomy technology.

The above research and innovation is a result of the unique collaboration between the departments for Electronic Systems, Engineering Cybernetics, Design and Marine Technology. The ferries and a corresponding Shore Control Lab (established by Department of Design) has become a unique research facility which attracts both master's students and PhD candidates. Furthermore,

the research activity within autonomous ships has been intensified by projects like *AutoFerry* financed by NTNU's Digital transformation initiative, the *Autosea project* (www.ntnu.edu/autosea), *Autosit project* (www.ntnu.edu/autosit), and the Center of Research-based Innovation *SFI Autoship* (https://www.ntnu.edu/sfi-autoship/).

- Egil Eide (Associate professor at IES)

3. References to the research (indicative maximum of six references)

1. Eide, Egil Sverre; Breivik, Morten; Brekke, Edmund Førland; Eriksen, Bjørn-Olav Holtung; Wilthil, Erik Falmår; Thyri, Emil Hjelseth; Veitch, Erik Aleksander; Alsos, Ole Andreas; Helgesen, Øystein Kaarstad; Johansen, Tor Arne. "Development and operation of the autonomous urban passenger ferry milliampere2". ICMASS 2023; Rotterdam, NL, 7 – 9 Nov 2023.

2. Brekke, Edmund Førland; Eide, Egil; Eriksen, Bjørn-Olav Holtung; Wilthil, Erik Falmår; Breivik, Morten; Skjellaug, Even; Helgesen, Øystein Kaarstad; Lekkas, Anastasios M.; Martinsen, Andreas Bell; Thyri, Emil Hjelseth; Torben, Tobias Valentin Rye; Veitch, Erik Aleksander; Alsos, Ole Andreas; Johansen, Tor Arne. "milliAmpere: An Autonomous Ferry Prototyp". Journal of Physics: Conference Series (JPCS) 2022 ; Vol. 2311.

3. Alsos, Ole Andreas; Veitch, Erik Aleksander; Pantelatos, Leander Spyridon; Vasstein, Kjetil; Eide, Egil; Petermann, Felix-Marcel; Breivik, Morten. "NTNU Shore Control Lab: Designing shore control centres in the age of autonomous ships." Journal of Physics: Conference Series (JPCS) 2022.

4. Vasstein, Kjetil; Brekke, Edmund Førland; Mester, Rudolf; Eide, Egil. «Autoferry Gemini: a real-time simulation platform for electromagnetic radiation sensors on autonomous ships.", IOP Conference Series: Materials Science and Engineering, 2020.

5. Reddy, Namireddy Praveen; Zadeh, Mehdi Karbalaye; Thieme, Christoph Alexander; Skjetne, Roger; Sørensen, Asgeir Johan; Aanondsen, Svein Aanond; Breivik, Morten; Eide, Egil. "Zero-Emission Autonomous Ferries for Urban Water Transport: Cheaper, Cleaner Alternative to Bridges and Manned Vessels." IEEE Electrification Magazine 2019 ;Vol. 7.(4) pp. 32-45.

6. Alfheim, Henrik Lemcke; Muggerud, Kjetil; Breivik, Morten; Brekke, Edmund Førland; Eide, Egil; Engelhardtsen, Øystein. "Development of a Dynamic Positioning System for the ReVolt Model Ship". IFAC-PapersOnLine 2018 ; Vol 51.(29) pp. 116-121.

4. Details of the impact (indicative maximum 750 words)

The concept of developing autonomous urban passenger ferries was initiated by associate professor Egil Eide in 2015 when the Trondheim fjord was approved as the world's first official test area for autonomous ships. With support from Center of Ecxellence NTNU AMOS (Center for Autonomous Marine Operations and Systems 2013 – 2023), a cross disciplinary research team was formed with scientific staff from Department of Electronic Systems (Egil Eide), Department of Engineering Cybernetics (Prof Edmund Brekke, Prof Tor Arne Johansen, and Morten Breivik), and Department of Marine Technology (Prof. Asgeir Sørensen).

The development and construction of the first ferry, "milliAmpere1" took place in 2016 and 2017 with contributions of master's students and PhD candidates from Department of Engineering

Cybernetics and Department of Marine Technology. After the launch in November 2017, the ferry was used for development and testing of sensor systems, control systems (Dynamic Positioning), situational awareness (STAW) and autonomous navigation. The project gained much attention in media and in the international research community.

As a natural follow up it was decided to build a full-scale ferry that could be certified for passenger transportation. The ferry "milliAmpere2" was launched in April 2021, and in the following year it was extensively tested and refined to ensure that it was ready to provide passenger transportation across the canal in Trondheim City.

Parallel to this the NTNU TTO conducted a process for making this technology commercially available. During the time period 2018 – 2020, NTNU Discovery and the Research Council of Norway supported the project a*Ferry* through the FORNY programme where the purpose was to verify the technology and analyze the market potential. This resulted in the spin-off company Zeabuz AS which was established in November 2019 to further develop and commercialize the technology.

Today, Zeabuz has 28 employees and has offices in Trondheim (HQ), Oslo and Stockholm. The company is developing and marketing a range products and solutions related to autonomy for waterborne transportation which will be important contributions to tackling future mobility challenges in urban areas. The European Commission anticipates in their Sustainable & Smart Mobility Strategy (2020) that transport by inland waterways and short sea shipping will increase by 25% by 2030. Autonomous and all-electric ferries will become an important component for implementing sustainable waterborne mobility.

In the time period between 2016 and 2023 a total of 95 master students and 18 PhD candidates have been involved in research directly related to or closely related to topics involved in the development of the ferries.

5. Sources to corroborate the impact (indicative maximum of ten references)

- Prof. Asgeir J. Sørensen, NTNU, phone: +47 918 97 457, e-mail: asgeir.sorensen@ntnu.no
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- Bjørn Kjærand Haugland, chairman of the board of Zeabuz AS, phone: +47 976 87 315, e-mail: bjorn@skiftnorge.no

IES 4

Institution: Norwegian University of Science and Technology (NTNU)
Administrative unit: Department of Electronic Systems (IES)
Title of case study: Constant envelope spreading for satellite communications
Period when the underpinning research was undertaken: 2011-2017
Period when staff involved in the underpinning research were employed by the submitting institution: 2005-2013
Period when the impact occurred: 2015--

1. Summary of the impact (indicative maximum 100 words)

A new satellite communication waveform has been developed and adopted by the International Telecommunications Union (ITU) in Recommendation ITU-R M.2092-1. The developed waveform has a smooth phase trajectory, allowing to minimise losses in the transmitter power amplifier while maintaining good spectral containment thereby protecting nearby channels from interference. The resulting spread spectrum based multiple access radio system (vessel to satellite) has near optimal capacity wrt. information theoretic limits. The waveform enables cost- and power efficient user equipment in Very High Frequency (VHF) data traffic between vessels and satellites, with direct impact on cost and system performance for end users including mariners (shipping, fisheries, marine transport, recreational), administrators (port, maritime and regulatory authorities) and service providers for maritime industry.

2. Underpinning research (indicative maximum 500 words)

A general technical problem in radio communications is to design a signal waveform that allows for an efficient implementation in radio frequency electronics while allowing for low complexity receiver algorithms and high system capacity. Many waveforms, e.g. Orthogonal Frequency Division Multiplex (OFDM) that is used in 4G and 5G systems, allow for high system capacity and low complexity algorithms, but requires a power amplifier that is relatively complex, costly, and is not power efficient (only a fraction of power supplied is emitted from the antenna, the rest becomes heat). Continuous phase waveforms allow for high power efficiency amplifier but incur a loss of throughput wrt. optimal ones. When used in Code Division Multiple Access (CDMA) systems, this loss diminishes.

The idea of continuous phase spreading sequences for CDMA originated with Prof. Ralf R. Müller, then employed at Department of Electronics and Telecommunication (later Dept. of Electronic Systems), NTNU, on his sabbatical at University of Erlangen, Germany, in 2009-2010. He wrote the initial paper [1] where he studied any losses in system spectral efficiency (i.e. total system throughput) if the spreading code of a CDMA system is constrained to have continuous phase. The initial results were promising, and an improved scheme was published in 2011 [2]. A multiuser detection receiver, allowing for the receiving of multiple simultaneous transmissions, needed for achieving the full system throughput was published in 2011 [3]. The main work up to this point was conducted by Prof. Muller (A. Lampe contributed on nonlinear models in the first paper). European Space Agency (ESA) funded in 2012 a study on CDMA based uncoordinated random access, including prof. Müller, G. Gallinaro of Space Engineering SpA, Associate Professor Pierluigi Salvo Rossi (NTNU: 2006-2008, 2014-2016, 2019--) and post-doc Kimmo Kansanen (NTNU: 2006--), as well as Dr. Riccardi de Gaudenzi and Dr. Nader Alagha from ESA. The results of the study were published in [4], indicating good performance and supporting the use of CDMA for ground to satellite random access. In the spring 2013, prof. Müller moved to Friedrich-Alexander-Universität (FAU) Erlangen, Germany. ESA also funded a further study on the system level performance of the continuous phase waveform,

published in [5], performed by Space Engineering (G. Gallinaro and S. Titomanlio), in collaboration with Prof. Müller and N. Alagha from ESA. The technique was proposed by ESA in the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) for further ITU adoption as part of the VHF Data Exchange System (VDES) for maritime communications with satellites. It was adopted in 2015 as part of Recommendation ITU-R M.2092-0 and revised later in 2019 as part of ITU-R M.2092-1.

The original research was within Prof. Müller's area of expertise, CDMA systems, and general interest in continuous phase waveforms, but was not otherwise supported by any research grant.

3. References to the research (indicative maximum of six references)

1. R. Müller, A. Lampe. Spectral efficiency of random CDMA with constant envelope modulation. Invited paper, International Journal of Electronics and Communications, vol. 65, no. 8, pp. 701–706, Aug. 2011. DOI:10.1016/j.aeue.2011.01.009

2. R. Müller. On random CDMA with constant envelope. IEEE Int'l Symp. on Inform. Theory (ISIT), St. Petersburg, Russia, Aug. 2011. DOI: 10.1109/ISIT.2011.6033828

3. R. Müller. Multiuser detection for continuous phase CDMA. IEEE-APS Topical Conf. on Antennas & Propagation in Wirel. Commun. (APWC), Turin, Italy, Sep. 2011. DOI: 10.1109/APWC.2011.6046787

4. G. Gallinaro, N. Alagha, R. de Gaudenzi, K. Kansanen, R. Müller, P. Salvo Rossi. ME-SSA: An advanced random access for the satellite return channel. IEEE Int'l Conf. Commun. (ICC), London, U.K., Jun. 2015. **DOI:** 10.1109/ICC.2015.7248429

5. G. Gallinaro, N. Alagha, R. Müller, S. Titomanlio. Quasi constant envelope CDMA for VHF maritime communications via satellite. Ka and Broadband Communications Conference (Ka), Trieste, Italy, Oct 2017. Pdf available on request.

6. Recommendation ITU-R M.2092-1 (2022), Technical characteristics for a VHF data exchange system in the VHF maritime mobile band (ITU-R) https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2092-1-202202-I!!PDF-E.pdf

4. Details of the impact (indicative maximum 750 words)

The research was the basis for proposing the technique for ITU adoption and being adopted in 2015 as part of ITU Recommendation. The research, through the results, documented in the publications demonstrated the characteristics and merits of the technology to European Space Agency for further studies on its performance. When it was evaluated as potential for maritime satellite communication use, it was taken by ESA via IALA to ITU. The technique is implemented in several VDES terminal and satellite payload products.

The research was initiated by the idea and personal effort of Prof. Müller, who developed the main concept for the waveform, and the design, as well as the detector algorithms. He also provided the system capacity analysis, as well as the ideas to utilise a single spreading sequence in a random access system. In the initial publication, A. Lampe contributed within nonlinear models. G. Gallinaro, S. Titomanlio (Space Engineering SpA) contributed system evaluations for publications [4]-[5], especially on the effects of amplifier nonlinearities. N. Alagha and de Gaudenzi (ESA) contributed with their knowledge of satellite access systems and supported in applying the idea within the VDES system parameters and constraints.

The community using maritime communications in the VHF spectrum, today often using the Automatic Identification System (AIS), which has created a great impact on vessel tracking, collision avoidance, and safety and security at sea. Users would be mariners (shipping, fisheries, marine transport, recreational), administrators (port, maritime and regulatory authorities) and service providers for maritime industry.

The AIS system can be partly attributed to affordable end-user equipment, often dominated by the high-power amplifier (HPA). The extension of AIS, called VHF Data Exchange System (VDES), is designed to offload and supplement AIS in high traffic areas, and described in the ITU Recommendation ITU-R M.2092-1. The proposed waveform, included in the recommendation, enables the use of a cost- and power efficient amplifier for VDES communication to satellite, making the system affordable to a larger population of users, with related improvement on safety.

Kongsberg Seatex produces today two VDES payloads (VST x50 & VST c50) that can be purchased for testing and demonstration purposes. The test results indicate the waveform performs as well as predicted. The IEC standard number for VDES has been allocated in 2023, and an international standard is expected in August 2026. Payloads supporting VDES and the reception of the continuous phase waveform are installed in two Norwegian satellites: NORSAT-2 (launched July 2017) and NORSAT-TD (launched April 2023). A wider deployment of terminal equipment on vessels is expected after IEC type conformity testing has been completed.

5. Sources to corroborate the impact (indicative maximum of ten references)

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NTNU IGP - Impact Case no. 01

Institution: Norwegian University of Science and Technology (NTNU)
Administrative unit: Department of Geoscience and Petroleum (IGP)
Title of case study: Better Resource Utilization in the 21st Century
Period when the underpinning research was undertaken: 2012-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2012-2022
Period when the impact occurred: 2012-2022

1. Summary of the impact

Establishment of 2 start-up companies: Solution Seeker (www.solutionseeker.com, 2013) and ComputerWell (www.computerwell.com, 2020), 1 software development project, ProDecs, has reached industrial investment; Wider acceptance and roll out of Integrated Operations in Equinor and Petrobras (2012-2017); Nation-wide survey of the Oil and Gas Industry in Norway, and development of research and education strategy in Oil and Gas for the whole NTNU (2016-2017); Establishment of BRU21: NTNU-Industry Research and Innovation Program in Digital and Automation Solutions for the Oil and Gas Industry (24 PhD/ PostDoc projects funded by the industry and 12 by NTNU) focusing on industry use cases and delivering results to the industry (2018-2022); Establishment of the BRU21 Academy to deliver continuous education in digitalization for the Norwegian Oil and Gas industry (2021-2022); Reaching internationally recognized top level in NTNU education in drilling automation, which impacts, through the NTNU graduates Norwegian drilling industry; Establishment of Brazil-Norway Collaboration Consortium on Production Optimization (2016-2023).

2. Underpinning research

The BRU21 impact case covers 3 large-scale research activities at IGP: the last 4 years of the SFI Center of Integrated Operations (IO Center, 2007-2015), the nationwide survey of the Norwegian Oil and Gas Industry (BRU21 report, 2016-2017) and the first 4.5 years of NTNU Research and Innovation Program in Digital and Automation Solutions for the Oil and Gas Industry (BRU21 program, 2018-present). Hosted and managed by IGP, these activities involved a multidisciplinary research task force from 8 departments/4 faculties at NTNU, external research partners SINTEF, IFE, Norwegian Research Council, Norwegian Petroleum Directorate, and over 20 companies from the O&G industry.

IO Center, managed by Professor Jon Kleppe (IGP), focused on Integrated Operations for the Oil and Gas industry: integration of people, organizations, work processes and information technology to make smarter decisions [R1]. In this evaluation we highlight two research directions specifically linked to NTNU and Phase II of the IO Center (2012-2015). Research on Production Optimization and Subsurface IO, was led by Professor Bjarne Foss (NTNU/ITK, member of IO Center). His team, together with Vidar Gunnerud (PhD student and PostDoc, currently CEO of Solution Seeker) focused on Data-Driven Production Optimization. Their research resulted in some of the first applications of Artificial Intelligence (AI) to production optimization in O&G installations (see, e.g., [R2]) – a novel approach for the O&G industry dominated, at that time, by model-based optimization methods. This research eventually led to the establishment of the startup company Solution Seeker (2013).

Another research direction with impact was Integrated Operations teamwork and capability development, conducted by NTNU, IFE, Sintef and industrial partners. Their research indicated the lack of proper tools for realizing new potentials of integrated operations. It focused on development of such tools and workflows. From the NTNU side, one of the active contributors

was Vidar Hepsø (Adjunct Professor at IGP, 2010-present + Equinor), see, e.g. research results presented in the monograph [R3]. Research from this area, combined with active dissemination through 4 IO Center conferences in 2012-2015 pushed forward the Integrated Operations mindset in the companies and led to impact in drilling, environmental monitoring, assessment of work practices and work processes.

The crisis of the O&G industry in 2015-2017 motivated the nationwide survey of the Norwegian O&G industry. It covered 41 companies and organizations in the Norwegian O&G industry and identified current challenges, technological needs, and ways in which academia can support the industry through research and education. The BRU21 report summarized these findings and defined NTNU strategy for research and education in Oil and Gas [R4]. This research was conducted by a team of IGP professors Egil Tjåland (team leader), Jon Kleppe, Sigbjørn Sangesland, Martin Landrø, and Arild Nystad (external consultant).

The BRU21 program – NTNU Research and Innovation Program in Digital and Automation Solutions for the Oil and Gas Industry was established by NTNU and industrial partners in 2018 to respond to the industry needs identified in the BRU21 report. Its focus is to enable higher efficiency, safety, and reduced environmental footprint of oil and gas production through digital and automation solutions and to support the industry transition to a sustainable energy future. It mobilizes multidisciplinary expertise across 8 departments/4 faculties at NTNU and, in cooperation with 9 industrial partners and the Norwegian Petroleum Directorate, produces research results for novel technological and organizational solutions. The program is managed by IGP: Ute Mann, the head of IGP, is the program owner, and professor Alexey Pavlov is the program manager. In this summary we highlight several research results from BRU21.

- Research on ultra-fast models (digital twins) of drill string dynamics conducted by Professor Sigve Hovda (IGP) in 2015-2022 (see, e.g. [R6]) led to the establishment of the start-up company **ComputerWell**.
- The research on virtual flow-metering by the PhD student Mathilde Hotvedt (ITK) and professor Lars Imsland (ITK) conducted in 2018-2022, focused on combining data-driven and model-based approaches for flow-metering through a choke valve [R6]. In particular, [R6, Chapter 5F] clarified that data-driven models must be frequently updated to adapt to new operating conditions quickly, which led to improvements in the **Solution Seeker's NeuralCompas software.**
- The research by Ph.D. student Semyon Fedorov (IØT) and professor Verena Hagspiel (IØT), conducted in 2018-2022, focused on the efficient development of small discoveries under significant uncertainties [R7]. The methodology developed by them based on Real Options Analysis turned out to be valuable for the sponsor of the project – OKEA ASA. It decided to develop these research results into software **ProDecs**.
- The research by PhD student Veronica Torres (IGP) and associate professor Kenneth Duffaut (IGP) conducted in 2018-2022, focused on the impact of data quality on Machine Learning for analysis of well-log data [R8]. The results turned out to be important for the project sponsor AkerBP – in 2022 it funded a project to further develop the obtained results.

Many more BRU21 research results were transferred directly to the program partner companies, where it is more difficult to trace their impact due to confidentiality. Also, the considered period (Aug 2018-2022) prevents us from demonstrating the full impact of the BRU21 research since, in the O&G industry, it usually takes years from research results to reach implementation. Several impact cases occurred in 2023, which is outside the reported period.

3. References to the research

[R1] J. Kleppe, IO Center: Final Report, NTNU, 2015, link to pdf
[R2] V. Gunnerud, B.A. Foss, K.I.M. McKinnon, B. Nygreen, Oil production optimization solved by piecewise linearization in a Branch & Price framework, Computers & Operations Research,

Volume 39, Issue 11, 2012, https://doi.org/10.1016/j.cor.2011.12.013
[R3] Tom Rosendahl, Vidar Hepsø, eds., Integrated Operations in the Oil and Gas Industry: Sustainability and Capability Development, DOI: 10.4018/978-1-4666-2002-5
[R4] E. Tjåland, S. Sangesland, M. Landrø, J. Kleppe. A. Nystad, eds., NTNU Strategy for Oil and Gas: What are the major challenges for the O&G industry on the Norwegian Continental Shelf in the future and the contribution from academia for solutions (The BRU21 report), NTNU, 2015
[R5] S. Hovda, Semi-analytical model of the axial movements of an oil-well drill string in deviated wellbores, Journal of Sound and Vibrations, Volume 417, 2018, https://doi.org/10.1016/j.jsv.2017.12.009
[R6] M. Hotvedt, On a hybrid approach to model learning, applied to virtual flow metering, PhD Thesis, NTNU, 2022, link to pdf
[R7] S. Fedorov, Cost-effective development of small discoveries on the Norwegian continental shelf, PhD Thesis, NTNU, 2022, link to thesis (pdf is available upon request due to IP protection)
[R8] V.C. Torres, Well-Log Database and Automation of Well Log Depth Matching by Using Analytical Methods and Deep Learning, PhD Thesis, NTNU, 2022.

3. Details of the impact

Solution Seeker: The company was established in 2013 as a spin-off from the IO-center at NTNU, where the founders, Vidar Gunnerud and Bjarne Foss, worked together. Almost all of the first employees (founders and co-founders) were involved in research activities at the IO-center. The IO-center was an important springboard for the company: the founders and co-founders met each other there, the network of partners was crucial to landing the first client contracts, and the research experience helped in the business development, see more in [i1]. While the background research was conducted at the Department of Engineering Cybernetics (ITK), the vital industry-academia ecosystem and network of the IO Center were established and managed by IGP. By 2022, Solution Seeker had: revenue 24.6MNOK, 27 employees in Norway and 3 employees in Brazil office; client list: 9 large international O&G companies; working with more than 15 assets worldwide. In 2018-2022, Solution Seeker CTO Bjarne Gunnerud co-supervised Mathilde Hotvedt's BRU21 PhD project [R6], which led to improvements in the operational process for NeuralCompass – the virtual metering product of Solution Seeker [i2]. The improvement concerned the frequency for updating NeuralCompass models, [R6, Ch.5F]. Mathilde is now working at Solution Seeker, leading the team responsible for delivering the company's AI flow products.

Integrated Operations (IO): The research on Integrated Operations and annual IO Center conferences in 2012-2015 led to the rollout of IO concepts and frameworks to Intelligent Drilling [i4], Integrated Environmental Monitoring [i5,i6], Assessment of Work Practices [i7, i8]. Centers of integrated operations are now well-established in Equinor [i4-i8] and Petrobras, [i9] – the companies that were active participants in the IO Center.

BRU21 report: The breadth of the survey of the Norwegian Oil and Gas Industry (41 companies and organizations) and the analysis conducted by the project team elevated this report to the status of NTNU Strategy for Oil and Gas [R4]. The report was presented to over 100 representatives from the industry, research institutions and government at the 1st BRU21 conference (2017), which was organized in collaboration with the Ministry of Petroleum and Energy. It was later presented to representatives of the management of OG21 ()

BRU21 program: The immediate impact of the publication of the BRU21 report was the BRU21 program funded by the industry (24 PhD projects) and by NTNU (12 PhD projects) – 2018-2022. It focuses on industry use-cases and delivers results to the industry (2018-2022). The impact of the BRU21 program is substantiated below. More info about the program can be found in [i11]

ComputerWell: The company is a start-up from IGP/BRU21 established in 2020. Its main product, DrillComputer, is based on algorithms developed by Professor Sigve Hovda (IGP) in 2015-2022. BRU21 program provided an arena for promoting the company and connecting it to BRU21 industrial network for business development and obtaining the first contracts. By 2022, the company had 2 employees and was supported by NFR, NTNU Discovery and Equinor & Techstars Energy Accelerator. More info can be found in [i3].

PRODECS: In 2022, OKEA invested 3.2MNOK in a project to develop findings and algorithms from [R7] into a software called ProDecs. In the same year, Norwegian Petroleum Directorate joined this development project. A confirmation can be found in the statement of OKEA's VP Thomas Lerdahl in [i10, p.12]. By 2022, ProDecs was supported by the acceleration program KongsbergHow, [i12].

BRU21 dissemination: To facilitate efficient dissemination to engineers in the industry, BRU21 established a novel method to reach engineers in the industry [R9] through short (1-5 minute) pitches of the latest research results, targeting engineers. Over 77 videos were distributed in 2021/2022 through LinkedIn, YouTube, video newsletters, and Facebook. More than 1300 copies of video reports were distributed across Norwegian O&G industry [i10]. This led to including BRU21 in the Technology strategy for the petroleum industry in Norway (OG21 report) in 2021 as a success case in the section Enablers for Innovation and Broad Implementation, [i11, p 82]. In 2022 BRU21 held its 2nd BRU21 conference for industry and academia [i13]. Alexey Pavlov (IGP) leads this activity.

BRU21 Academy: BRU21 Academy was established in 2022 to accelerate the transfer of BRU21 research results to the industry [i14]. It is a continuing education Master's program in Digitalization and Automation in the Energy Sector. It consists of 5 specialization courses: Remote operations; Digital solutions for planning and optimization maintenance; Petroleum Cybernetics for engineers and managers; Digital Twins for Managing Safety and Reliability of Systems and Demonstrating Safety of Novel Solutions. In 2022 the BRU21 Academy received funding by the Ministry of Higher Education and Skills (HK Direktoratet) for 2023/24. Pilot courses were already given individually in 2021 and 2022. Professors Jørn Vatn (MTP), Alexey Pavlov (IGP), Milan Stanko (IGP), Vidar Hepsø (IGP) and Elena Parmiggiani (IDI) contribute to the BRU21 Academy.

BRU21 Education: BRU21 research and expertise in drilling automation are transferred to NTNU students through Drillbotics – an international SPE student competition in autonomous drilling. Since 2017 NTNU Drillbotics team took the 1st place in 2018, 2021 and 2022 [i15]. NTNU is the only university with such a track record in the physical rig category. NTNU Drilbotics team was coached by BRU21 professors A. Pavlov (IGP, Team lead), S. Sangesland (IGP), T.B. Gjersvik (IGP) and L. Imsland (ITK). Since 2017, Drillbotics teams at NTNU and the University of Stavanger (UiS) shared their design reports (after the competition) to increase knowledge build-up in our teams. This cross-fertilization contributed to the victories of NTNU team and, victories of UiS teams in 2021-2022 in the virtual rig category.

Brazil-Norway Collaboration Consortium on Production Optimization was established in 2016 with the primary objective to further increase the quality of Production optimization research and education at NTNU Department of Engineering Cybernetics and Department of Geoscience and Petroleum by developing cooperation with Federal University of Santa Catarina (UFSC), and also Brazilian and Norwegian industry partners. Its activities were funded by NFR INTPART project and resulted in 5 annual 2-day Production optimization workshops; academic exchanges, 3 PhD projects with a double degree, a number of joint publications and software development (FieldOpt), and closer collaboration between Brazilian and Norwegian researchers. This project

was co-managed by Prof. Morten Hovd (ITK) and Alexey Pavlov (IGP). As a concrete impact example, Solution Seeker benefitted from this consortium [i2]: It was an important arena for presenting technology advancements and for networking in Brazil. It helped Solution Seeker maintain its presence and decade-long relationship with important actors in Brazil's O&G industry. It was likely because of these relationships that Solution Seeker got a large contract with Libra (a consortium led by Petrobras) in 2021. This enabled Solution Seeker to establish an office in Brazil.

5. Sources to corroborate the impact

[i1] Solution Seeker website/Our story: https://www.solutionseeker.no/company/our-story/
[i2] Bjarne Grimstad, CTO of Solution Seeker. Personal communication. bjarne.grimstad@solutionseeker.no (the email is not to be published)
[i3] ComputerWell website/about us: https://computerwell.com/about-us/
[i4] Iversen, Fionn , Gressgård, Leif Jarle, Thorogood, John L., Balov, Mohsen Karimi, and Vidar Hepsø. "Drilling Automation: Potential for Human Error." *SPE Drill & Compl* 28 (2013): 45–59. doi: https://doi.org/10.2118/151474-PA
[i5] Hepsø, Vidar , Låte, Mona , Gramvik, Geir , Johnsen, Ståle , Nilssen, Ingunn , and Harald Wesenberg. "Integrated Environmental Monitoring in Daily Operations." Paper presented at the SPE Intelligent Energy International, Utrecht, The Netherlands, March 2012. doi: https://doi.org/10.2118/150054-MS
[i6] Wesenberg, Harald , Hepsø, Vidar , and Anders Hermansen. "Advances in Integrated Environmental Monitoring." Paper presented at the SPE Intelligent Energy Conference & Exhibition, Utrecht, The Netherlands, April 2014. doi: https://doi.org/10.2118/167860-MS
[i7] Lilleng, Trond , Øyen, Mette , Farestvedt, Unn , Engelsen, Harald , Nordbø, Hilde , Vennes, Berit, Revheim, Aleksander , Seim, Ole , and Teresa Halvorsen. "Integrated Operations in Statoil - From Ambition to Action." Paper presented at the SPE Intelligent Energy International, Utrecht, The Netherlands, March 2012. doi: https://doi.org/10.2118/150418-MS
[i8] Drøivoldsmo, A.. , and E.. Nystad. "The Man, Technology and Organisation MTO Function Allocation Method Used for Optimal O&M Staffing in a Greenfield Project." Paper presented at the SPE Intelligent Energy International Conference and Exhibition, Aberdeen, Scotland, UK, September 2016. doi: https://doi.org/10.2118/181102-MS
[i9] Claudio Benevenuto de Campos Lima, José Adilson Tenório Gomes, Integrated Operations in Petrobras: A Bridge to Pre-Salt Achievements, In Integrated Operations in the Oil and Gas Industry: Sustainability and Capability Development, Tom Rosendahl, Vidar Hepsø (eds.), Link
[i10] BRU21 video report 2021-2022, link to pdf
[i11] BRU21 program website: www.ntnu.edu/bru21
[i12] ProDecs: better projects investment decisions, https://www.ntnu.edu/bru21/prodecs
[i13] BRU21 Conference 2022: https://www.youtube.com/watch?v=bLYKwNBre3A
[i14] BRU21 Academy webpage: https://www.ntnu.edu/bru21/bru21-academy
[i15] Drillbotics competition website: www.drillbotics.com. List of past winners: https://drillbotics.com/archives/

NTNU IGP - Impact Case no. 02

Institution: Norwegian University of Science and Technology (NTNU)
Administrative unit: Department of Geoscience and Petroleum (IGP)
Title of case study: Unlocking the Deep Sea Mining potential in Norway
Period when the underpinning research was undertaken: 2012 - 2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2012 - 2022
Period when the impact occurred: 2017-2022

1. Summary of the impact

Since 2012, researchers at NTNU have contributed to increasing the knowledge about the technological requirements for a potential future deep-sea mining industry in Norway. Major impact has been related to defining the resource potential of (yet-to-find) mineral resources on the extended Norwegian continental shelf which has been vital for the industrial interest for developing deep-sea mining in Norway and has led to the opening of a defined area on the Norwegian EEZ for commercial exploration in January 2024. NTNU established an interdisciplinary Deep Sea Mining Pilot as part of strategic research area NTNU Oceans, led by IGP. Further, an industry-wide competence project including 14 Norwegian industry partners and 3 research partners, as well as partnership in two EU (FP7 and H2020) projects, BlueMining and BlueNodules. The EU Deep Sea Mining School gathered ca 30 participants in Trondheim in 2022 for a week of lectures and excursions related to DSM topics. Our activities and results have been decisive for the establishment of NMM (The Norwegian Forum for Marine Minerals). Our researchers have been important contributors to reports on the State of the Art for technology as input documents to the Environmental Impact Assessment EIA for the opening process. The recent focus on DSM has led to NTNU sustainability project TripleDeep.

2. Underpinning research

Research related to deep-sea mining at NTNU has been interdisciplinary and covered several important research areas. However, here we will focus on the research led by the research group on Mineral Production and HSE and the relevant key research insights, that still indicate the extent of the interdisciplinarity in our research. The first Key research insight refers to the early-stage initiation of the DSM research at NTNU. As the interest in mineral resources on the ocean floor grew, there was a significant need to estimate the potential for discovering economically viable mineral deposits on the Norwegian extended continental shelf. Hence, a resource potential estimation of yet-to-find mineral resources along the Mohns- and Knipovich ridges was initiated in 2012 as a joint project between NTNU and industrial partners (Nordic Mining and Statoil). The initial research led to a project report published in 2014, that demonstrated a vast potential for seafloor massive sulphides along the two ridges. Key researchers were Professor Emeritus Richard Sinding-Larsen and Professor Steinar Løve Ellefmo at NTNU.

The next stages of research related to deep-sea mining has been carried out under the umbrella of the NTNU Ocean´s Deep-sea Mining Pilot Program (DSM-pilot), led by Professor Steinar Løve Ellefmo at Dept. of Geoscience and Petroleum. The main perspective of the DSM-pilot was on the value chain with parallel focus and emphasis on the humanities and environmental sciences as supporting or secondary processes crucial and needed for a future responsible extraction of minerals from the deep ocean floor. A total of 24 PD- and PhD candidates have been involved in the pilot program, filling a total of 26 positions. Projects funding were a mix of RCN and EU-funded research projects (>50%), and others were directly funded through the NTNU Oceans. One of the projects was the RCN funded competence project MarMine (Exploitation technologies for marine minerals on the extended Norwegian continental shelf) led by Associate Professor Kurt Aasly at Dept. of Geoscience and Petroleum. During the research cruise as part of the MarMine-project (Ludvigsen et al. 2016) a

significant amount of mineralized material was collected from the Loki´s Castle Mounds on the Arctic Mid-Ocean Ridge, within Norwegian Extended Continental Shelf. The sampled material was used as basis for the mineralogical and mineral processing research with purpose to evaluate the need for new solutions for mineral processing or if traditional methods are sufficient.

Conventional processing using froth flotation proved to be less successful than anticipated (Kowalczuk et al. 2018, 2019). Although a bulk sulphide concentrate could be produced, the complex mineralogy made it impossible to achieve selective separation of the different valuable sulphide minerals (e.g., chalcopyrite and isocubanite in the case of copper) or to separate these minerals from pyrite. Concerns related to the availability of so-called representative samples from the deposits have been raised and it was stressed that the sampled material was limited and did not represent the interior of the mineralization and hence not representative for what to be expected in the real mineral processing plant. The research on mineral processing properties of SMS (processability) was initiated in 2017 and is still ongoing under the RCN funded Green Platform project *EMINENT* led by Adepth Minerals, but with significant contribution by our research group on this topic. Key researchers are Associate Prof. Kurt Aasly, Prof. Pshem Kowalczuk, Prof. Rolf Arne Kleiv, Dr. Ben Snook, Dr. Kristian Drivenes, and Dr. Valdislav Slabov

This work continued into and ran in parallel to the work on defining favourable areas and their characteristics which fed into analyses of yet-to-find resources along the Arctic Mid-Atlantic ridge inside Norwegian jurisdiction (Juliani 2019; Juliani and Ellefmo 2018a, 2018b). In two projects, attempts have been made to find links between geoscientific observations onshore and observations offshore (Pryadunenko et al. 2022; E. Ryan 2023; E. J. Ryan et al. 2023). This has increased the understanding of the ore forming processes both onshore and offshore and will provide input to both exploration strategy development and mineral resource potential estimations.

The next key research insight is related to the modelling and simulation of future mining systems as part of the MarMine project as well as related research under the Deep-Sea Mining Pilot at NTNU. The research was initiated in 2015 and is still ongoing under the NTNU Sustainability project TripleDeep. Key researchers at our research group are Professor Steinar Løve Ellefmo, Dr. Maxime Lesage, and PhD candidate Raoul Schmidt.

Additional projects under the Deep-sea Mining Pilo looked in to potentials of significant impact on biogeochemical and ecological processes on the seafloor. And on the major environmental concerns regarding the generation of plumes near the seabed and in the water column.

Environmental ethics was another part of the DSM-pilot have were ethical aspects of deep-sea mining were explored. The focus was on normative questions involved in technological development, exemplified with deep-sea mining. The aim was to provide knowledge needed to make ethically responsible decisions about deep sea mining and other activities involving environmental risk. Finally, one project was targeted on the development of the international laws, regulations and state of technologies relevant for deep sea mining throughout the last 50-60 years. This historical study aimed to understand the changes that have taken place during the last half century about values, interests, and possibilities, how they came about and how they influenced the law of the sea and to understand the positions, e.g., of different nations, and how they have developed and changed over time.

3. References to the research

Ellefmo, SL and Søreide F (2019) Quantifying the Unknown: Marine Mineral Resource Potential on the Norwegian Extended Continental Shelf. Book, open access e-book at https://doi.org/10.23865/noasp.81

Ellefmo, SL; Aberle-Malzahn, N; Hagspiel, V; Ingulstad, M; **Aasly, K** (2022) Marine minerals' role in future holistic mineral resource management. Geological Society Special Publication (526)

Ellefmo, SL; Kuhn, T (2021) Application of Soft Data in Nodule Resource Estimation. Natural Resources Research. Vol 30.(2)

Juliani, CJ; Ellefmo, SL (2019) Multi-scale Quantitative Risk Analysis of Seabed Minerals: Principles and Application to Seafloor Massive Sulfide Prospects. Natural Resources Research Vol 28.

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Kleiv, RA; Thornhill, M (2022) Deep-Sea Mining–A Bibliometric Analysis of Research Focus, Publishing Structures, International and Inter-Institutional Cooperation. Minerals Vol 12.(11)
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Kowalczuk, PB; Manaig, DO; **Drivenes, K; Snook, B; Aasly, K; Kleiv, RA (**2018) Galvanic Leaching of Seafloor Massive Sulphides Using MnO2 in H2SO4-NaCl Media. Minerals.Vol 8.(6)
Kowalczuk, PB; Bouzahzah, H; **Kleiv, RA; Aasly, K** (2019) Simultaneous leaching of seafloor massive sulfides and polymetallic nodules. Minerals Vol 9.(8)
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Sture, Ø; **Snook, B**; Ludvigsen, M (2019) Obtaining hyperspectral signatures for seafloor massive sulphide exploration. Minerals Vol 9.(11)
Tjåland, E; Ellefmo, SL; Aasly, K; Gjersvik, TB; Fichler, C. (2022) Oil and Gas Technologies as Key Elements for a Viable Deep Sea Mining Industry. I: Proceedings of ASME 2022 41st International Conference on Ocean, Offshore & Arctic Engineering Volume 10 : Petroleum technology. The American Society of Mechanical Engineers (ASME). ISBN 978-0-7918-8595-6.

4. Details of the impact

Since 2012, researchers at NTNU have contributed to increasing the knowledge about the technological requirements for a potential future deep-sea mining industry in Norway. Since the activities started with the definition of the resource potential of undiscovered (yet-to-find) mineral resources along the extended Norwegian continental shelf, in 2012, the numbers have been used in many instances. It is fair to claim, that along with the actual discoveries of hydrothermal chimneys within the Norwegian EEZ by the University of Bergen, the publication of the expected in-situ values of the *undiscovered* mineral resources by NTNU researchers, have been among the main driving forces towards the opening of part of the Norwegian EEZ for mineral exploration.

Following the resource potential assessment, our group was awarded an industry-wide competence project, MarMine, co-funded by the RCN and industry partners. IGP was the coordinating partner, NGU and NIVA contributed as research partners in a consortium with 14 Norwegian industry partners. The outputs from the MarMine project and related activities in the Deep-Sea Mining Pilot, including EU projects and NTNU strategic funding has contributed to make impact on the decision processes towards the opening decision made in the Norwegian Storting on January 9th, 2024. As part of our focus on DSM, IGP was part of a consortium with e.g. TU-Delft and TU-Bergakademie Freiberg that organized the EIT International Summer School - From Dredging to Deep-Sea Mining. The DSM school was arranged at NTNU in September 2022 with 50 participants from various industry and universities in Europe.

NTNU has played a significant role in establishing and leading the Norwegian Forum for Marine Minerals (NMM) since it´s initiation in 2019. The secretariat has been located at NTNU up to 2023. NMM is an association of industry and research actors who work together to develop knowledge and expertise, and a Norwegian industry aimed at sustainable and responsible exploration and extraction of marine mineral resources.

As part of the opening process for deep-sea mining within the Norwegian EEZ, IGP contributed to State-of-the-Art reports to the Environmental Impact Assessment for the opening process on the

Norwegian Extended Continental Shelf, with the *Technology Report* and the *Economic and Social effects of deep-sea mining activities.*

5. Sources to corroborate the impact

Chronicles:

Ellefmo, SL; Aasly, K; Søreide, F (2020) Ligger vår fremtid på havdypet? Adresseavisen. https://www.midtnorskdebatt.no/meninger/kronikker/2020/05/24/Ligger-v%C3%A5r-fremtid-p%C3%A5-havdypet-21895232.ece

Schjølberg, I; **Ellefmo, SL**; Carson, SG (2018) Mineralutvinning på havbunnen. Adressavisen 26.05.2018. https://www.midtnorskdebatt.no/meninger/kronikker/2018/05/26/Mineralutvinning-p%C3%A5-havbunnen-16771204.ece

Ludvigsen, M; **Aasly, K; Ellefmo, SL** (2016) Gull på havbunnen? Dagens næringsliv 15.08.16. https://www.dn.no/industri/havbruk/miljo/gull-pa-havbunnen/1-1-5708634

News articles:

Ellefmo, SL; Aasly, K; Ludvigsen, M; Søreide, F (2020).Mineralutvinning på havbunnen? Skipsrevyen. Volum 50.(4) s. 44-46

Ellefmo, SL (2020). Kvantifisering av det ukjente. Geo365.no, 22.07.2020. https://geo365.no/dyphavsmineraler/kvantifisering-av-det-ukjente/

Aasly, K; Ellefmo, SL; Ludvigsen, M (2016) På skattejakt til Jan Mayen. Under Dusken Nr 7, 2016-04-19. NTNU. https://dusken.no/media/publications/2016/UD-2016-7.pdf

Ellefmo, SL; Carson, SG; Haugan, I (2015). Vi kjenner månen bedre enn havbunnen. Gemini [Fagblad] 2015-05-05. https://gemini.no/2015/05/vi-kjenner-manen-bedre-enn-havbunnen-var/

Reorts/studies:

Laugesen, J, **Aasly, K, Ellefmo, SL,** (2021) Teknologirapport havbunnsmineraler (No. 2020–1218, rev. 2–1231487). DNV AS.

Galloway, T, **Aasly, K, Ellefmo, SL**, Fuentes, D, von der Leyen, K, Skonhoft, A, Wold, MF, (2022) Økonomiske og sosiale virkninger av havbunnsmineralvirksomhet (No. Rapport fra Asplan Viak 635474-01). Asplan Viak, NTNU, Oslo.

Ludvigsen, M; **Aasly, K; Ellefmo, SL**; et al. (2016) NTNU Cruise reports no 1 - MarMine cruise report Arctic Mid-Ocean Ridge 15.08.2016 - 05.09.2016. Trondheim: NTNU 2016 120 s. NTNU Cruise reports (1)

Media:

Ellefmo, SL (2013). Norge kan sitte på en ny gullgruve. NRK Distriktsnyheter Midtnytt. https://tv.nrk.no/serie/distriktsnyheter-midtnytt/201312/DKTL98121613/avspiller.

Abstracts and presentations:

Ellefmo, SL; Søreide, F; **Sinding-Larsen, R** (2014). Marine Minerals and Ocean Mining Potential in the North Atlantic - Results. UMI 2014; 2014-09-21 - 2014-09-28

NTNU IGP – Impact Case no. 03

Institution: Norwegian University of Science and Technology (NTNU)
Administrative unit: Department of Geoscience and Petroleum (IGP)
Title of case study: IGP's Contribution for Capacity Building in Tunneling and Hydropower in Nepal
Period when the underpinning research was undertaken: 2012 - 2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2012 - 2022
Period when the impact occurred: 2012 - 2022

1. Summary of the impact Department of Geoscience and Petroleum (IGP), previously the Department of Geology and Mineral Resources Engineering (IGB), has had long-lasting collaboration with Nepal, contributing to the capacity building of Nepal within tunnelling and hydropower engineering originally starting with one year Post Graduate Study Program (1982 – 1993) and a MSc Program in Hydropower Development (1994 – to date) at NTNU. In addition, in 2021 IGP has opened a new window of collaboration with Pashchimanchal Campus, Institute of Engineering (IOE-WRC) of Tribhuvan University (TU) of Nepal through NORHED II Project 70141 6; Capacity Building in Higher Education within Rock and Tunnel Engineering. Professors from the research unit "Engineering geology and rock mechanics" of IGP are mainly involved in the collaboration. All together over 120 MSc graduates under Hydropower Development Program at NTNU and 38 graduates from the MSc program in rock and tunnel engineering that was launched at IOE-WRC in 2020 have been produced. In addition, 6 PhD graduates have been produced and 8 PhD fellows are working on the respective research at IGP. Out of all graduates over 95 percent working in Nepal and hold many leading positions both in public, private and education sectors. The contribution made by NTNU within rock and tunnel engineering and hydropower development education is considered as one of the most successful stories of academic contributions made by Norway to underdeveloped countries. There is at least one NTNU hydropower graduate in each of hydropower project built in Nepal.

2. Underpinning research

The use of underground space in Nepal is enormous, particularly for hydropower and infrastructure development. However, the active tectonic movement and dynamic monsoon cause the rock mass in the Himalaya relatively weathered, fractured, weak and schistose. Predicting rock mass quality, analysing stress induced problems associated to both rock burst and plastic deformation and predicting inflow and leakage potential often have been found extremely difficult during planning stage. Considerable discrepancies have been found between predicted and actual rock mass conditions, resulting in significant cost and time overrun for most of the tunnelling projects. Finding innovative solutions for quantifying geological uncertainties and assessing risk are therefore key factors for cost effective and optimum future tunnelling through Himalayan rock mass. The research that has been conducted by Nepalese PhD fellows from this department have been groundbreaking in identifying the most crucial aspect of tunnel stability problems, identifying factors affecting the stability, research on the sensitivity of existing methods used to analyse geological uncertainties and development of methodologies and standards suitable to tunnelling through Himalayan rock mass. Some of the groundbreaking PhD research that have been completed from IGP (IGB) in regards with Himalayan geology and rock mass are:

- Analysis of Engineering Geological Uncertainties Related to Tunnelling in Himalayan Rock Mass Conditions (Krishna Kanta Panthi, 2006)

- Stress induced problems in Himalayan tunnels with special reference to squeezing (Gyanendra Lal Shrestha, 2006)
- Stability of tunnels subject to plastic deformation – a contribution based on the cases from the Nepal Himalaya (Pawan Kumar Shrestha, 2014)
- Applicability of Unlined/Shotcrete Lined Pressure Tunnels for Hydropower Projects in the Himalaya (Chhatra Bahadur Basnet, 2018).

Currently there are four PhD fellows at the department who have their research orientation on the Himalayan geology, geo-tectonic and rock mass. The research outcomes will further enhance the existing methodologies, establish new methodologies and guidelines. In addition, the fellows are aiming to highlight the important aspects of rock and tunnel engineering research to be focused on future. The MSc education within rock and tunnel engineering at IOE-WRC and research outcome of the PhD projects will play pivotal role in the development of new standards, enhancement of cost effectiveness and long-term sustainability of underground excavations (tunnels, shafts, underground caverns) as well as cut slopes at the topographic slopes.

- Krishna Kanta Panthi, Professor, Department of Geoscience and Petroleum of NTNU.
- Pawan Kumar Shrestha, Visiting Professor, Paschimanchal Campus, Institute of Engineering (IoE-WRC), Tribhuvan University (TU), Nepal.
- Chhatra Bahadur Basnet, Visiting Associate Professor, Paschimanchal Campus, Institute of Engineering (IoE-WRC), Tribhuvan University (TU), Nepal.
- Tek Bahadur Katuwal, PhD fellow, Department of Geoscience and Petroleum of NTNU.
- Sailesh Adhikari, PhD fellow, Department of Geoscience and Petroleum of NTNU.
- Bimala Piya Shrestha, PhD fellow, Department of Geoscience and Petroleum of NTNU.
- Hare Ram Timalsina, PhD fellow, Department of Geoscience and Petroleum of NTNU.

3. References to the research

There have been many groundbreaking research publications that have been made withing rock and tunnel engineering by the listed scholars above. Six selected manuscripts that have been published between 2012 and 2022 are given below as reference:

Panthi K. K. 2022. Capacity Enhancement in Rock and Tunnel Engineering in Nepal. Nepal Journal of Science and Technology, vol 20, issue 2. https://doi.org/10.3126/njst.v20i2.45776

Panthi K. K. and Broch E. 2022. Underground Hydropower Plants. In: Letcher, Trevor M. (eds.) Comprehensive Renewable Energy, 2nd edition, vol. 6, pp. 126–146. Oxford: Elsevier. http://dx.doi.org/10.1016/B978-0-12-819727-1.00077-7

Panthi K. K. and Basnet C. B. 2021. Fluid Flow and Leakage Assessment Through an Unlined/Shotcrete Lined Pressure Tunnel: A Case from Nepal Himalaya. Rock Mechanics and Rock Engineering, vol. 54, pp. 1687–1705. https://doi.org/10.1007/s00603-020-02350-6

Panthi K. K. and Basnet C. B. 2018. Evaluation of earthquake impact on magnitude of the minimum principal stress along a shotcrete lined pressure tunnel in Nepal. Journal of Rock Mechanics and Geotechnical Engineering, vol. 11, pp. 920-934. http://dx.doi.org/10.1016/j.jrmge.2019.06.003

Basnet C. B. and **Panthi K. K.** 2018. Roughness evaluation in shotcrete-lined water tunnels with invert concrete based on cases from Nepal. Journal of Rock Mechanics and Geotechnical Engineering, vol. 10, pp. 42-59. http://dx.doi.org/10.1016/j.jrmge.2017.07.006

Shrestha P. K. and **Panthi K. K.** 2015. Assessment of the effect of stress anisotropy on tunnel deformation in the Kaligandaki project in the Nepal Himalaya. Bulletin of Engineering Geology and the Environment, vol. 74, pp. 815–826. http://dx.doi.org/10.1007/s10064-014-0641-5

4. Details of the impact

The most underpinning research results are/will be associated to the development of methodologies for stability assessment of tunnels, road cut slopes and tunnel construction methods suitable to Himalayan rock mass conditions. The developed approaches are / will reflect to the actual ground conditions, cost effectiveness and sustainable rock engineering solutions since these methods are/will be developed in consideration with topographic, geologic, and geo-tectonic environment of the Himalayan region. The research approach adopted in general are as following:

- Data collection and field mapping at the different tunnelling projects of Nepal.
- Comprehensive laboratory assessment of the rock samples at the state-of-art rock mechanics laboratory at IGP-NTNU.
- Use of state-of-art tools and software programs such as 3DEC, FLAC3D, Rocscience etc.
- In-dept stability assessment, critical thinking, and uncertainty analysis.
- Production of high-quality journal manuscripts and publication.

Project impacts

The IGP-NTNU experience indicates that the graduate students considerably contributed to the socioeconomic development of the country. IGP-NTNU graduates of Nepal are positioned in leading roles within rock and tunnel engineering sphere in Nepal. This experience of IGP-NTNU is good evidence that the graduates produced by IoE-WRC through NORHED II Project will also have considerable impacts to the Nepalese society by:

- The production of high-quality graduate engineers within rock and tunnel engineering, who are/will be contributing to the development of transport infrastructure and renewable hydropower energy in Nepal. In addition, four faculties of IoE-WRC who are pursuing PhD research under NORHED II project will contribute to the education and research within this field in Nepal for many decades to come.
- Women empowerment through guaranteed (reserved) access to MSc education within this field, including scholarship and tuition fee.
- Internationalizing MSc education and faculty exchanges within rock and tunnel engineering from the neighbouring countries like Bhutan, India and Myanmar.
- Establishing foundation for the long-term education and research between IGP-NTNU and IoE-WRC in issues related to landslide hazards, rock engineering, tunnelling, and geo-environment of the mountainous countries like Nepal and Norway.

Beneficiaries

The main beneficiaries are the country Nepal, Nepal Electricity Authority, Hydropower Industry of Nepal, Public institutions, Municipalities, Road and Railway Departments of Nepal, Education institutions of Nepal, Department of Mines, Mining Industries etc.

Evidence

- All PhD fellows of Nepal graduated from IGP-NTNU are key players in the Nepalese society.
- Many MSc graduates from the MSc in Hydropower Development Program of NTNU are in leading positions in different organizations in Nepal.
- Four of the MSc graduates from IOE-WRC through NORHED II program have already been enrolled in the national pride “Fast Track Project” immediately after the completion of MSc education.
- Over 10 MSc graduates from IOE-WRC through NORHED II program have permanent positions at the Department of Roads of Nepal.

- Many MSc graduates from IOE-WRC through NORHED II program have started working in the different municipalities.
- Many MSc graduates from IOE-WRC through NORHED II program have started working in the consulting and developer organization within hydropower sector.
- Some MSc and PhD graduates have opened their own consulting and contractor services.

5. Sources to corroborate the impact

1. Dr. Pawan Kumar Shrestha
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[NTNU Department of Structural Engineering] [case number]

Institution: NTNU
Administrative unit: Department of Structural Engineering
Title of case study: The Tretten bridge collapse
Period when the underpinning research was undertaken: 2005 - 2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2005 - 2022
Period when the impact occurred: 2022 - date

1. Summary of the impact

From the introduction of the report issued by The Norwegian Safety Investigation Authority (NSIA) "Rapport vei 2023/03 August 2023" (Delrapport 1 om kollapsen av Tretten bru i Øyer kommune 15. august 2022 | shk (havarikommisjonen.no)):
On the morning of 15 August 2022, Tretten Bridge in Norway collapsed and fell into the river of Gudbrandsdalslågen and onto the E6 highway, after having been in operation for approx. 10 years. NSIA, together with an external expert group, has carried out technical investigations with respect to the collapse. Due to the fact that it is important for society and for the continued operation of existing timber bridges to clarify the technical reasons for the collapse, NSIA has chosen to present the results from this extensive work in sub report 1.

The bridge collapsed without warning, for traffic loads much smaller than the design load. Luckily, no-one was seriously injured. Shortly after the Tretten bridge collapse, the Norwegian road authorities decided to close 14 other timber bridges which had some similarities to Tretten bridge.
The major work (investigation) to clarify the technical reason of the collapse of Tretten Bridge was performed by the department during the year after the collapse. The investigation material and results were openly published and lessons learned and new knowledge are brought into the organizations dealing with safety an usability of engineering structures. .

2. Underpinning research

The investigation showed that Tretten bridge had reduced strength prior to the collapse. There was no trace of traffic overload, and the most probable cause of the collapse is damage accumulated over time i.e. fatigue. The failure mode was block (shear) pull-out failure. The bridge was designed according to regulations from the national road authorities and the Norwegian national standard for timber structures at that time (NS 3470-1), which did not have any regulations regarding block (shear) pull-out failure.

The department has performed research on fundamental issues regarding the strength, stiffness, dynamics and design of timber bridges since the first modern timber bridge in Norway was opened in 1996 (Evenstad).
Material properties for numerical simulation by FEM has been experimentally determined and characterized for softwood of pine and spruce. The material properties and numerical models for long term effects (creep and dimensional changes) from varying moisture and temperature, have been evaluated and numerical models developed.
The strength and stiffness pre-stressed timber decks, stability and splicing of wooden bow-bridges have been explored. Strength and stiffness of connections like dowel joints with slotted-in steel

plates have been studied and evaluated both for static and dynamic response. Experimental research for fatigue design of dowel joints and fracture mechanics has been conducted.

The research has covered most of the technical aspects in timber bridge building and has been led by Professor Kjell Arne Malo. The following persons have delivered relevant PhD theses:
Kristian Dahl: 2009, Mechanical properties of clear wood from Norway spruce.
Vanessa Angst:2011, Moisture induced effects on the capacity of screws and threaded bars in timber structures.
Natalie Labonnote: 2012, Damping in Timber Structures.
Haris Stamatopoulos: 2016, Withdrawal Properties of Threaded Rods embedded in Glued-Laminated Timber Elements
Martin Cepelka: 2018, Splicing of Large Glued Laminated Timber Elements by Use of Long Threaded Rods.
Anna Ostrycharczyk: 2018, Network arch timber bridges with light timber deck on transverse crossbeams.
Francesco M. Massaro: 2019, Stress-Laminated Timber Decks in Bridges Pre-stressing system, long-term effects and modelling.
Katarzyna Opstapska: 2020, Fracture in wood of Norway spruce. Experimental and numerical study.
Saule Tulebekova, 2022, Dynamics of tall timber buildings.

All these PHDs are, after their PhD period, working as researchers or professional consultants, except Stamatopoulos and Massaro who, after Post. Doc. periods were employed by NTNU, and Tulebekova who currently has a Post Doc position. In addition, approximately 25 Master theses have been carried out on timber bridge topics during the last decennium.

Several projects have underpinned the research and knowledge building in timber bridges, the two largest research projects were *Durable Timber Bridges (*DuraTB *2014 – 2017, with project report on* https: https://www.diva-portal.org/smash/record.jsf?pid=diva2%3A1116787&dswid=2511*), and Dynamic Response of Tall Timber Buildings under Service Load (DynaTTB 2018 – 2022, website:* https://www.dynattb.com). DuraTB covered many timber-bridge specific issues, while DynaTB had a thorough evaluation of dowel joints where the obtained results are still subjects to future publications.

3. References to the research

Malo, Kjell Arne; Massaro, Francesco Mirko; Stamatopoulos, Charalampos: Exploring fatigue rules for timber structures in Eurocode 5. I: International Conference on Timber Bridges ICTB 2021PLUS - Conference proceedings. Biel, Switzerland: Bern University of Applied Sciences 2022 ISBN 9783906878126. s. 231-242, https://www.bfh.ch/dam/jcr:727819b5-bc88-4348-b386-4c71cbc79023/28-ictb2021-malo.pdf

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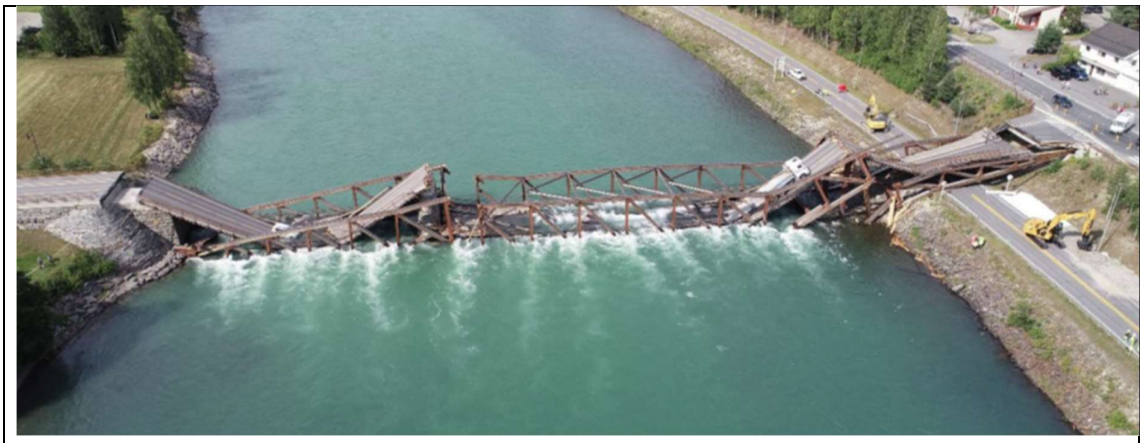
4. Details of the impact

On the morning of 15 August 2022, Tretten Bridge in Norway collapsed and fell into the river Gudbrandsdalslågen and onto the E6 highway. Not only one of the main river crossings was lost, also the European highway (E6) which is the main route to north and north-western parts of Norway, was blocked and the traffic had to be redirected through narrow roads in residential areas at Tretten. The bridge collapsed without warning, for traffic loads much smaller than the design load.



The department has been continually active in the modern development of timber structures from the beginning of the new millennium, especially on use of wood in larger timber buildings and timber bridges. Much effort in research has been put on the material behaviour of wood, where the anisotropic structural properties for stiffness and strength both for short- and long-term load exposure as well as varying moisture conditions have been characterized with respect to effective use by the Finite Element Method (FEM).
On the structural level the behaviour of joints has been given most attention, as joints in wood usually necessitate removal wood materiel in locations where it is most needed (holes for bolts and dowels, steel parts etc.) The wood material is hence usually most utilized in and around connections and that is the reason for our attention on connections. Wood as a structural material has high strength in the grain direction, while it is weak for load exposure in normal directions. Wood is also a relatively brittle material and hence clever and competent use of wood especially in and around connections is demanded.
Although considerable effort has been put on numerical modelling of wood in timber structures, the anisotropic nature of wood together with its large statistical variation of properties, as well as the very large number of needed parameters make the practicality and reliability of numerical simulations less than with industrial produced materials. Therefore, confidence in results requires also experimental evidence. Experimental and numerical research in parallel are therefore needed in most cases.
The test facilities at all scales at the department give the ability to validate nearly all kinds of structural response to a large range of load exposures. For the impact case with the collapsed Tretten bridge, both material properties and the structural failure in a diagonal structural element were validated by experimental testing using the laboratory facilities at the department. The testing gave the necessary strength information and hence the computational modelling of the bridge collapse could be validated.

The impact case is well documented in the official report from the investigation of the bridge collapse, and is available as Vedlegg B from Delrapport 1 om kollapsen av Tretten bru i Øyer kommune 15. august 2022 | shk (havarikommisjonen.no).
(Report is in Norwegian, for a presentation of the case in English, please consider:
K.A. Malo: The Tretten bridge collapse. How could it happen? Conf.paper, 27. Internationales Holzbau-Forum IHF 2023, Innbruck, 29.11 - 1.12.2023, Austria. https://studntnu-my.sharepoint.com/:b:/r/personal/kam_ntnu_no/Documents/Shared%20with%20Everyone/K%20A%20Malo%20Tretten%20Bridge_Referat_IHF_2023_EN%20v6.pdf?csf=1&web=1&e=5T2uFZ)

As it may be noted from Vedlegg B from the report, the impact on the safety of critical road infrastructure is not coming from research on a single topic, or on some specialities; it is the broad and comprehensive competence in all relevant issues connected to the safety and structural

behavior of, in this case, timber bridges. This is a necessary premise for a thorough investigation of a major accident and is necessary to get confidence in the outcome of an investigation and thereby acceptance of the results in society.

Immediately after the NSIA report publication, the Norwegian Public Road Administration started to incorporate the recommendations and calculation methods applied in the report into their handbooks and guidelines for timber bridges, with guidance from the experts at the department. All the fourteen closed bridges were recalculated and have been physically checked, and the result is to date that 4 bridges are reopened for full traffic, 7 bridges are reopened with reduced traffic load, and 3 bridges are still closed. 3 of the bridges cannot be strengthened and will be demolished, while 2 or 3 of the bridges will be strengthened and reopened for full traffic load. More details are available on: https://www.vegvesen.no/om-oss/presse/aktuelt/2023/10/status-for-arbeidet-med-oppfolgingen-av-tretten-bru/

The impact of research published in scientific journals and new knowledge obtained from investigation of accidents are collected and evaluated to improve our society in the long term. In Europe, the European Commission gives a mandate to a professional standardization body like CEN, the European Committee for Standardization, to improve legislation and regulations taking the latest knowledge into consideration.
This work is performed by experts who are collecting and classifying all available knowledge, representing the interests of society with respect to safety and applicability. To put this work into active use, it is necessary to incorporate research into the regulations and tools used by professional partners like engineers, architects, contractors, and developers. At the department, many persons are highly active experts in this joint effort to generate the second suite of the Eurocodes - the European technical standards for our built environment. The impact case investigation members are and have been active as: Head of Norway delegation CEN/TC250/SC5 committee on timber structures, Convenor EN 1995-2 (CEN/TC250/SC5 WG6 Timber Bridges), Leader and members of Norwegian mirror committee SN/K 077 for CEN/TC250/ EN 1995 Standardization of timber structures, Member SN/K370 Mirror committee for CEN/TC 250 Complete suite of Eurocodes EN1990-EN1999, Member CEN/TC250/Horizontal Group Bridges, and Member CEN/TC250 Ad Hoc Group Fatigue. The investigation experts bring the outcome of the case investigation to the new Eurocodes and the building regulations for the future.

5. Sources to corroborate the impact

The impact case has been given much attention in the press world-wide. However, the impact of the work performed at the department is in general not known to the public, as NSIA requires that all public relations shall be handled by NSIA and all experts from the department had to sign a declaration of confidentiality.
The following person are representing various parties in the society and had various roles with respect to the impact case, i.e. overall safety authorities, professional consultants in structures, manufacturer of timber structures, road authorities, and national and international standardization.
Per Olav Hetland, Havari-inspektør, Statens Havarikommisjon (NSIA), PerOlav.Hetland@nsia.no
Magne Bjertnæs, CEO, SWECO Lillehammer AS, magne.bjertnaes@sweco.no
Rune Abrahamsen, CEO, Moelven Limtre AS, Rune.Abrahamsen@moelven.no
Hauke Burkart, Standard Norge, hbu@standard.no
Tor Håvard Ellingsen, Statens vegvesen, Vegdirektoratet, tor.havard.ellingsen@vegvesen.no
Nils Audun Karbø, Statens vegvesen, nils.karbo@vegvesen.no
Phillip Dietsch, Professor, Karlruhe Institute for Technology, dietsch@kit.edu

[Name of the institution and name of the administrative unit] [case number]

Institution: The Norwegian University of Science and Technology
Administrative unit: The Department of Structural Engineering
Title of case study: An accurate and cost-efficient model for ductile failure of thin metallic material
Period when the underpinning research was undertaken: 2017-2023
Period when staff involved in the underpinning research were employed by the submitting institution: 2017-2023
Period when the impact occurred: 2019-

Summary of the impact (indicative maximum 100 words)
In this case, we have developed an accurate and cost-efficient model capable of predicting the initiation of ductile failure in finite element analyses of thin-walled metallic components. This model, referred to as the Through-Thickness Regularization (TTR) model, allows engineers from the automotive industry and their supply chain to accurately design critical aluminium or steel components involved in crash-relevant structures. This, in turn, contributes to the development of safe, sustainable and cost-efficient electric vehicles.

1. Underpinning research

The research described in this case was the result of a long-term initiative carried out at the SIMLab group. Associate Professor David Morin and Associate Professor Miguel Costas have carried out the necessary development and validation behind the proposed model supported by Professor Odd Sture Hopperstad and Professor Magnus Langseth.
The main aim of this project has been to develop and validate a ductile failure model capable of predicting the initiation and the propagation of cracks and fracture in thin-walled metallic components used in automotive structures. With the TTR model, our goal was to propose a simplified approach, compared to existing industry standards, while still being capable of retaining the necessary accuracy in engineering applications.
Our research has the following outputs:
First, a new regularization scheme based on a structural understanding of ductile failure was proposed. This model utilizes the capability of shell elements, used in large-scale analyses of structures, to capture the transition from pure bending to pure membrane loading and its impact on the ductility of metallic materials. The TTR model was validated against experiments carried out under both quasi-static and dynamic loading conditions on a 6XXX aluminium extruded profile.
Second, this model was applied to high-strength steel used in the civil engineering industry to benchmark its applicability in another business sectors than the automotive one.
Finally, we have presented our model in several conferences where other materials, such as different advanced high-strength steels, were used as validation cases.
Our various validation activities have shown that this model fulfilled its intended purpose.

Key researchers:

- David Morin, Associate Professor (main developer)
- Miguel Costas Morin, Associate Professor
- Odd Sture Hopperstad, Professor
- Magnus Langseth, Professor

Contextual information:

- This case study is built on a long-lasting activity at the research group SIMLab which started in the early 90s by Professor Magnus Langseth and Professor Odd Sture

Hopperstad. While the research itself belongs to the field of structural and mechanical engineering, the proposed model required a continuous interaction with the automotive industry and their supply chain involved in the SFI-SIMLab (2007-2014) and SFI-CASA (2015-2023) centres hosted at the department of structural engineering at NTNU.

3. References to the research

- Miguel Costas, David Morin, Odd Sture Hopperstad, Tore Børvik, Magnus Langseth, A through-thickness damage regularisation scheme for shell elements subjected to severe bending and membrane deformations, Journal of the Mechanics and Physics of Solids, 2019, 190-206
- Håkon Johannessen, Oddvar Hestetræet Johannessen, Miguel Costas, Arild Holm Clausen, Johan Kolstø Sønstabø, Experimental and numerical study of notched SHS made of different S355 steels, Journal of Constructional Steel Research, 2021, 182, 106673
- Miguel Costas, David Morin, Magnus Langseth, Modelling and Simulation of Impact in Stiffened Aluminium Panels Using Damage Regularisation, ASIDIC2019, Aerospace Structural Impact Dynamics International Conference, 2019
- Joakim Johnsen, Jens Kristian Holmen, Gaute Gruben, David Morin, Magnus Langseth, Calibration and application of GISSMO and *MAT_258 for shell element simulations of high-strength steel, 12th European LS-DYNA ® conference, 2019
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- Joakim Johnsen, Jens Kristian Holmen, Gaute Gruben, David Morin, Magnus Langseth, Calibration and Application of GISSMO and *MAT_258 for Simulations Using Large Shell Elements, 16th International LS-DYNA ® Users Conference, 2020
-

4. Details of the impact (indicative maximum 750 words)

The research conducted by the Department of Structural Engineering at NTNU has been a result of extensive collaboration between researchers and engineers working at the industrial partners of SFI-CASA. Beside the scientific work underpinning the TTR model, we spent large amount of time in technology transfer to the industrial partners of the centre. This step was necessary to first ensure that our model fulfil the requirements of engineering practices and to provide the necessary education of our industry partners. Once accepted by several of our user-partners, our model was implemented into the commercial versions of LS-DYNA and VPS-PAMCRASH, two of the leading finite element solvers on the market. Anyone using these solvers can then use our model free of charge thus expanding the targeted users far beyond the initial consortium of SFI-CASA. As per today, the TTR model is used daily at some of these companies to design metallic components.

In 2018, we were awarded a FORNY project by the Research Council of Norway to evaluate the commercialization potential of a spin-off company where material cards (e.g., the parameters involved this model) could be developed. In this project we benchmarked the TTR model to several models used by industry in terms of accuracy and calibration cost. The result of this project was the establishment of ENODO, a spin-off company from the SIMLab research group.

Beside the impact on industry partners, we have recently brought back this model into our teaching activities. The TTR model is lectured as part of the Impact Mechanics course (TKT4128) and is incorporated into the SIMLab-project during the fall. We therefore train around 30-40 students every year in using our model. Furthermore, several master theses are carried out every spring using this model as the standard for modelling fracture in metals. These master theses are an opportunity to evaluate how such modelling framework could be extended to other business sectors.

5. Sources to corroborate the impact

Statement from the Scientific Advisory Board of SFI-CASA (19 September 2018):
There is clear evidence that the research addresses the relevant problems of the partners in the 3 main areas of the Centre. This provides the basis for innovation. A set of tools has been developed, based upon the Centre's expertise in materials and component testing, in constitutive modelling of deformation and failure and in numerical simulation. The Centre is arguably unique in their ability to understand and to address material behaviour across the length scales that feeds into computational tools to predict the behaviour of structural components. … The SAB applauds the focus on practical computational methods such as the calibration of shell responses to include failure mechanisms (such as rivet joints and sheet necking). The Centre is world leading in this regard.

[Name of the institution and name of the administrative unit] [case number]

Institution: The Norwegian University of Science and Technology
Administrative unit: The Department of Structural Engineering
Title of case study: Virtual Mitral Valve Surgery Using Echocardiographic Recordings
Period when the underpinning research was undertaken: 2018-2023
Period when staff involved in the underpinning research were employed by the submitting institution:
Period when the impact occurred:

Summary of the impact (indicative maximum 100 words)
In this case, we have developed methods to create digital replicas of patients' mitral valves from echocardiographic images and perform structural simulations in a finite element framework. By developing such methods, we have non-invasively assessed the biomechanics of the mitral valve and perform in silico surgeries, which helps the surgeons with the planning of surgical interventions and enables the development and testing of novel devices prior to first-in-human trials.

1. **Underpinning research**
   The research described in this case was undertaken in 2018 by Victorien Prot and was in continuity with his previous research carried out with Bjørn Skallerud.

The main aim of this project has been to develop and validate a numerical pipeline to create patient-specific mitral valve digital-twins from 3D echocardiographic recordings and study them in a finite element framework. With a developed pipeline, our goal was to study mitral valve regurgitation, by implementing disease-specific material properties and patient-specific boundary conditions. Our research has the following outputs:

First, a pipeline to create patient-specific mitral valve geometries and study them in a finite element framework by incorporating patient-specific boundary conditions, loading, and disease-specific material properties has been developed. For the degenerative mitral valve disease Barlow's disease, the results show that mitral valve closure is highly dependent on both annular dilation and material properties.

Second, a pipeline to perform in silico annuloplasty on patient-specific mitral valves has been developed. The annuloplasty procedures are modelled with accurate annular and papillary muscle dynamics by segmentation of post-operative echocardiographic recordings. These annuloplasty rings can be scaled in any desired shape and size, enabling the implantation of the optimal size for each patient.

Finally, we have developed a general annuloplasty procedure that is based on several postoperative recordings of the mitral annulus and papillary muscle movement, which can be used to perform in silico annuloplasty on pre-operative patients yet to have surgery. The developed in silico annuloplasty procedures have been performed on eight Barlow's mitral valves, where the annuloplasty ring size was varied until optimal coaptation area for each patient has been achieved.

Findings show that moderate annular reductions may be sufficient to achieve proper valve closure as compared to conventional surgery.

Key researchers:

- Hans Martin Aguilera, PhD candidate, joined in 2020 and defended in 2023.
- Victorien Prot, Associate professor, joined in 2011.
- Bjørn Skallerud, Professor.

Contextual information:

- This area of research is highly multidisciplinary involving structural engineering, medical technology, and medicine. It required a strong collaboration between the department of structural engineering at NTNU and the department of heart disease at Haukeland University hospital in Bergen.
-

3. References to the research

- Hans Martin Aguilera, Stig Urheim, Bjørn Skallerud, Victorien Prot
- Influence of annular dynamics and material behavior in finite element analysis of Barlow's mitral valve disease
- 2021
- Journal of Elasticity, 145 (1-2), 163-190, https://doi.org/10.1007/s10659-021-09829-5

- Hans Martin Aguilera, Stig Urheim, Robert Matongo Persson, Rune Haaverstad, Bjørn Skallerud, Victorien Prot
- Finite element analysis of mitral valve annuloplasty in Barlow's disease
- 2022
- Journal of Biomechanics, 142, 111226, https://doi.org/10.1016/j.jbiomech.2022.111226

- Hans Martin Aguilera, Robert Matongo Persson, Rune Haaverstad, Bjørn Skallerud, Victorien Prot, Stig Urheim
- In silico analysis provides insights for patient-specific annuloplasty in Barlow's disease
- 2023
- JTCVS open, 13, 95-105, https://doi.org/10.1016/j.xjon.2023.01.007

4. Details of the impact (indicative maximum 750 words)

The research conducted by the Department of Structural Engineering at NTNU and the Department of Heart Disease at Haukeland University hospital in Bergen has been a result of extensive collaboration between researchers, cardiologists, and surgeons. The Department of Structural Engineering was responsible for data processing, modelling, and simulations, while the collaborators at Haukeland were responsible for patient recruitment and data collection. The research hypotheses and questions were formulated in a collegial manner.

The research underpinned increases the knowledge and the understanding of the dynamics of primary mitral valve regurgitation. It delivers new perspectives in the choice of artificial rings for mitral reconstructive surgery.

Through regular meetings and research visits, our collaborators at the hospital benefited and were influenced by our research results. In addition, our results have been presented at the Norwegian Association for Cardiothoracic Surgery, Spring meeting 2022 and other conferences. Hans Martin Aguilera was also selected to give a talk at The American Association for Thoracic Surgery, Mitral Conclave workshop in 2022 in Boston, on our novel method to perform patient specific annuloplasty in Barlow's disease.

5. Sources to corroborate the impact

Statement from Professor Rune Haaverstad, Seksjonsleder, Thoraxkirurgisk seksjon Hjerteavdelingen Haukeland Universitetssykehus

"The clinical impact has been 1) an increased pathophysiological understanding of the development of type Barlow mitral valve disease and 2) fundamental in the choice of surgical treatment in Barlow mitral valve disease. In detail, the most important part of Barlow disease, that most often is seen in young patients between 30-60 years old, is the annular dilatation in the late phase of the cardiac cycle causing a severe mitral valve leakage. When the biomechanical knowledge is taken into account, the importance of an appropriate sized and tailored commercially available mitral annuloplasty ring is fundamental in the reconstructive surgical treatment. This added knowledge provides valuable information that is very useful for the heart surgeon in his/her planning of the surgical procedure."

NTNU, EPT, IMPACT CASE 1

Institution: NTNU
Administrative unit: Department of Energy and Process Engineering, EPT
Title of case study: Enabling Zero Carbon Combustion
Period when the underpinning research was undertaken: 2012 - 2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2013 - 2022
Period when the impact occurred: 2013 - 2022

1. Summary of the impact

The gas turbine industry is a vital driver of innovation, economic growth, jobs, trade, and mobility in the EU in both the aviation and power generation sectors. It is a multi-billion Euro high-technology industry whose future competitiveness depends on a new generation of creative engineers who can accelerate the development of new innovations needed for flexible, efficient power generation and sustainable aviation.

The Thermo-fluids (TF) group at EPT has built up a dedicated laboratory space and obtained substantial funding through a number of programmes to conduct fundamental research targeted at the major scientific challenges in gas turbine combustion, which include combustion instabilities (thermoacoustics), reducing harmful emissions, and flame stabilization, which are all particularly relevant for the future shift to zero carbon combustion. The strong participation of industry in many of these joint projects demonstrates their need to improve their understand the fundamentals, and the need to train future experts.

The timeframe for the development of this technology is very long. New engines can take decades to develop, and engines designed and built today may remain in service for up to 50 years. Therefore, while we can demonstrate the seeds of long-term impact today, the contribution of the group's work in this area is likely to grow over time.

2. Underpinning research

The underpinning research within the TF group has been conducted by Professors Dawson, Worth, Moeck, and Adjunct Professor Gruber.

Professors Dawson and Worth were the first team to develop a laboratory scale annular combustor capable of generating self-excited azimuthal modes [1], while both working at the University of Cambridge in 2012. Dawson and Worth were employed in Professor positions at EPT in 2013 and 2015 respectively, and continued this work. This breakthrough, enabled the study of this type of combustion instability for the first time under practically representative conditions, opening up a new research area. The continuation of this work at NTNU involves the use of carbon-free fuels, and the world's only lab scale annular facility capable of generating such modes under pressurised operating conditions [2].

Professor Moeck has worked in the area of thermoacoustic instabilities and non-linear dynamical systems at the University of Berlin, the University of Michigan, and Laboratoire EM2C at Ecole Centrale Paris, joining NTNU in 2017. He has pioneered new understanding of swirling flames [3], modelling and understanding of can-annular and annular systems, and new methods of analysis based on the novel application of Bloch theory to study systems with discreet rotational symmetry

[4]. His work has made the computation and modelling of unstable modes computationally tractable, greatly improving our ability to predict these.

Professor Andrea Gruber is a Senior Research Scientist at SINTEF Energy Research and since 2018 an Adjunct Professor at NTNU. His research interests are in the development and deployment of massively parallel direct numerical simulations (DNS) and Large Eddy Simulation (LES) to gain insight and accurately predict turbulent reactive flows of relevance to gas turbines. He has pioneered new understanding of flame flashback and stabilization [5], including cases and configurations relevant for zero-carbon fuels [6].

Working together, this group of Professors have developed and run a highly productive laboratory space, generated significant research output spanning experimental, numerical, and theoretical disciplines, interacted closely with several major European gas turbine manufacturers, and successfully attracted major national and international funding.

Working closely with SINTEF Energy major national projects include: a Research Council of Norway (RCN) funded center for environmentally friendly energy NCCS (Dawson, Gruber, 2017-2025) on pre-capture carbon capture and storage, hydrogen combustion; An RCN, CLIMIT programme funded BIGH2 Phase 3 project (Dawson, Gruber, 2017-2021) on fuel flexibility and ammonia combustion; An RCN funded Low Emission Research Centre (Dawson, Worth, Gruber, Moeck, 2019-2026) on zero-carbon combustion; An RCN Industrial project REHEAT2H2 (Moeck, Gruber, 2019-2023) on clean and stable hydrogen reheat combustion in gas turbines. Competitive national funding for fundamental science has also been obtained through a RCN funded FRIPRO Researcher project STA (Worth, 2019-2024) on zero-carbon combustion.

Major international projects include: an ERC starting grant TAIAC (Worth, 2016-2021) on thermoacoustic instabilities in annular systems; an ERC synergy grant HYROPE (Dawson, Gruber, 2024-2030) on staged zero carbon combustion at elevated pressure; A Marie Curie ITN ANNULIGHT (Dawson, Moeck, Worth, 2017-2022).

3. References to the research

[1] Worth, N.A. and Dawson, J.R., 2013. Modal dynamics of self-excited azimuthal instabilities in an annular combustion chamber. *Combustion and Flame*, *160*(11), pp.2476-2489.
[2] Indlekofer, T., Ahn, B., Kwah, Y.H., Wiseman, S., Mazur, M., Dawson, J.R. and Worth, N.A., 2021. The effect of hydrogen addition on the amplitude and harmonic response of azimuthal instabilities in a pressurized annular combustor. *Combustion and Flame*, *228*, pp.375-387.
[3] Candel, S., Durox, D., Schuller, T., Bourgouin, J.F. and Moeck, J.P., 2014. Dynamics of swirling flames. *Annual review of fluid mechanics*, *46*, pp.147-173.
[4] Mensah, G.A., Campa, G. and Moeck, J.P., 2016. Efficient computation of thermoacoustic modes in industrial annular combustion chambers based on Bloch-wave theory. *Journal of Engineering for Gas Turbines and Power*, *138*(8), p.081502.
[5] Wiseman, S., Rieth, M., Gruber, A., Dawson, J.R. and Chen, J.H., 2021. A comparison of the blow-out behavior of turbulent premixed ammonia/hydrogen/nitrogen-air and methane–air flames. *Proceedings of the Combustion Institute*, *38*(2), pp.2869-2876.
[6] Rieth, M., Gruber, A., Williams, F.A. and Chen, J.H., 2022. Enhanced burning rates in hydrogen-enriched turbulent premixed flames by diffusion of molecular and atomic hydrogen. *Combustion and Flame*, *239*, p.111740.

4. Details of the impact

The European gas turbine industry is a multi-billion-euro industry, and of huge importance. The aviation industry for example contributes significantly to the European economy, employing around 5 million people. The ongoing research work conducted within the TF group contributes significantly towards keeping this industry at the forefront of technology, helping it to continue to grow while transitioning to sustainable operation, providing more and better jobs in Europe. The work also promotes technical innovations in many other related applications, also driving growth.

The use of net-zero fuels in future stationary gas turbines and aeroengines is extremely novel and current designers face challenges due to a lack of data, experience, and well adapted engineering tools. Hydrogen and ammonia combustion are critical technologies, and the focus of a significant number of ongoing major European projects. The strong participation of industry in these demonstrates the need to train future experts. The work conducted within the TF group addresses this need and will result in the following long-term scientific impacts:

(i) The creation of high-quality knowledge and scientific understanding of net zero fuel combustion physics, and the theoretical and numerical approaches which can be deployed in a predictive capacity to mitigate stability issues, evidenced through high quality scientific output. For example, over the last 5 years Professors Dawson, Worth, Gruber, and Moeck have published 91 papers in high impact journals.

(ii) Strengthened human capital in Research and Innovation (R&I) through doctoral training with a focus on producing engineers with exceptional qualifications and skills, resulting in enhanced knowledge circulation and talent across the European R&I landscape, evidenced through doctoral students and postdoctoral researchers trained within the research group. Over the last 5 years 13 PhD students and 12 postdoctoral researchers have been trained and supervised on relevant topics, and have entered the European workforce in academia, research institutes, and industry.

(iii) Enhanced knowledge diffusion and R&I quality due to the availability of cutting-edge tools and methods, improving Europe's long-term competitiveness, evidenced through close collaboration with industry in a wide variety of research projects (as detailed in section 2). The research work conducted in the TF group contributes towards positioning Europe as a world leader in training future combustion engineers for a low carbon future, and as a centre of excellence in hydrogen and ammonia combustion science, and thermoacoustics.

Combustion instabilities are currently a major hindrance to the adoption of net zero fuels and other low emission technology. Hydrogen combustion is noisy and ammonia combustion faces major emissions issues. This forces designers to be conservative in developing systems, limiting the design space, and potentially compromising efficiency. Our work focuses on the rapid diagnosis and elimination of thermoacoustic instabilities, with tools and knowledge that can be deployed even late in the design process. As such it will lead to breakthroughs in how combustion instabilities are resolved during the industrial design process. If designers have the tools and knowledge eliminate thermoacoustic instabilities when they occur, they will have the freedom to develop and explore more radical and innovative design solutions, to also optimise combustion systems for weight, size, and harmful pollutants for example.

The direct participation of major European gas turbine manufacturers (Siemens Energy, Thomassen Energy, Ansaldo Energia, SAFRAN, Rolls Royce) in projects lead by the TF group demonstrates the relevance and applicability of the work, and will ensure that the understanding, tools, and methods developed can be directly integrated into existing industrial processes. This is likely to drive innovation and the generation of IPR. While our work focusses on gas turbine applications, the tools and knowledge are directly relevant for a wider range of combustion

devices including rocket engines and industrial furnaces. Additionally, the research conducted at the TF group holds significant relevance for the industrial heat sector, particularly in the decarbonization challenges faced by key industries such as steel, cement, glass, and aluminium. These sectors collectively contribute to 1% of the global CO2 emissions and are actively exploring hydrogen fuelling as a potential solution, which is susceptible to thermoacoustic instabilities. The adoption of hydrogen for power generation and aviation will help to nurture the growing hydrogen economy, which has the potentially to completely reshape the European energy landscape.

5. Sources to corroborate the impact (indicative maximum of ten references)

1. Professors (Dawson, Gruber) were invited to participation in research strategy meetings at Siemens Energy, helping to define their future research agenda.
2. Professor Dawson invited to contribute to the *Hydrogen in a future low carbon society* white paper.
3. Professor Gruber invitation to participate in the definition of ammonia emissions standards, helping to shape the future utilisation of this as a fuel.
4. Group activities were instrumental in establishing a collaboration between Ansaldo Energia and Equinor.

NTNU, EPT, CASE NUMBER 2: EXIOBASE

Institution: NTNU
Administrative unit: EPT
Title of case study: EXIOBASE
Period when the underpinning research was undertaken: 2007-now
Period when staff involved in the underpinning research were employed by the submitting institution: 2007-now
Period when the impact occurred: continuously

1. Summary of the impact

EXIOBASE is the outcome of three EU projects (EXIOPOL, CREEA, DESIRE) and is maintained by NTNU/IndEcol since the end of the projects. It is the only global environmentally extended input-output database with a clear focus on sustainability issues (carbon footprint, environmental hot-spot or sustainable supply chain analysis) and a consistent sector classification. EXIOBASE is a tool that is used for scientific research and by multiple consultant companies for spend based carbon footprinting. It is also used by several policy institutions, including the Norwegian Department of Public Procurement (DFØ), the Norwegian Miljødirektoratet, the Swedish EPA and the European Environment Agency.

2. Underpinning research

Environmentally extended multiregional input-output (EE MRIO) tables have emerged as a key framework to provide a comprehensive description of the global economy and analyze its effects on the environment. Of the available EE MRIO databases, EXIOBASE stands out as a database compatible with the System of Environmental-Economic Accounting (SEEA) with a high sectorial detail matched with multiple social and environmental satellite accounts. The overall objective of EXIOBASE is to provide a global EE MRIO database with high suitability for environmental analysis. Starting from the initial version, EXIOBASE aimed to be suitable for answering sustainability questions of the EU and its main trading partners as well as for major global economies.

To this date, 3 main versions of EXIOBASE have been developed, all outcome of a specific EU project.
EXIOBASE 1 - outcome of the fp6 EXIOPOL project (2007-2011) http://www.feem-project.net/exiopol/scheda.php?ids=2
EXIOBASE 2 - outcome of the fp7 CREEA project (2011-2014)
https://cordis.europa.eu/project/id/265134/reporting
EXIOBASE 3 - outcome of the fp7 DESIRE project (2012-2016)
https://cordis.europa.eu/project/id/308552/reporting

The projects were led by TNO (Netherlands), with NTNU having a major role in the development of the database (WP leader of the relevant work package). Other partners involved in the project (Uni Leiden, Vienna Economic University, 2.0LCA, Wuppertal Institute, SEC Vienna, etc) were mostly data providers and/or users of the database.

Since the end of the projects, NTNU/IndEcol has been the sole maintainer of the database, with over 50k downloads on Zenodo (https://doi.org/10.5281/zenodo.5589597), over 400 citations of the method paper describing the latest release (https://onlinelibrary.wiley.com/doi/full/10.1111/jiec.12715) and multiple policy uses (see below). Key personal involved in the development of the database at NTNU are:

Prof. Edgar Hertwich https://www.ntnu.edu/employees/edgar.hertwich
Prof. Richard Wood https://www.ntnu.edu/employees/richard.wood
Dr. Konstantin Stadler https://www.ntnu.edu/employees/konstantin.stadler

3. References to the research

Stadler, Konstantin, Richard Wood, Tatyana Bulavskaya, Carl-Johan Södersten, Moana Simas, Sarah Schmidt, Arkaitz Usubiaga, et al. "EXIOBASE 3: Developing a Time Series of Detailed Environmentally Extended Multi-Regional Input-Output Tables." Journal of Industrial Ecology 22, no. 3 (2018): 502–15. https://doi.org/10.1111/jiec.12715.

Wood, Richard, Michael Grubb, Annela Anger-Kraavi, Hector Pollitt, Ben Rizzo, Eva Alexandri, Konstantin Stadler, Dan Moran, Edgar Hertwich, and Arnold Tukker. "Beyond Peak Emission Transfers: Historical Impacts of Globalization and Future Impacts of Climate Policies on International Emission Transfers." Climate Policy 20, no. sup1 (April 8, 2020): S14–27. https://doi.org/10.1080/14693062.2019.1619507.

Ivanova, Diana, and Richard Wood. "The Unequal Distribution of Household Carbon Footprints in Europe and Its Link to Sustainability." Global Sustainability 3 (ed 2020). https://doi.org/10.1017/sus.2020.12.

Wood, Richard, Daniel Moran, Konstantin Stadler, Diana Ivanova, Kjartan Steen-Olsen, Alexandre Tisserant, and Edgar G. Hertwich. "Prioritizing Consumption-Based Carbon Policy Based on the Evaluation of Mitigation Potential Using Input-Output Methods." Journal of Industrial Ecology 22, no. 3 (2018): 540–52. https://doi.org/10.1111/jiec.12702.

Hamilton, Helen A., Diana Ivanova, Konstantin Stadler, Stefano Merciai, Jannick Schmidt, Rosalie van Zelm, Daniel Moran, and Richard Wood. "Trade and the Role of Non-Food Commodities for Global Eutrophication." Nature Sustainability 1, no. 6 (June 2018): 314. https://doi.org/10.1038/s41893-018-0079-z.

Wood, Richard, Karsten Neuhoff, Dan Moran, Moana Simas, Michael Grubb, and Konstantin Stadler. "The Structure, Drivers and Policy Implications of the European Carbon Footprint." Climate Policy 20, no. sup1 (April 8, 2020): S39–57. https://doi.org/10.1080/14693062.2019.1639489.

4. Details of the impact

Policy use/impacts:

EXIOBASE provide consumption-based accounts for the 44 major global economies and 5 rest of the world regions. Building the database requires harmonization of national statistics with international data sources (e.g. trade, energy statistics, etc.). This harmonization leads to deviation of the national statistics from the original data sources. National statistical agencies object to these changes when implementing the database in their official statistics, e.g. for official national carbon footprints. In order to address this issue, we developed a coupled model approach, which allows to calculate consumption-based accounts that fully respected national statistical data, whilst accurately modelling impacts abroad (via EXIOBASE).

This approach was first developed for the Swedish PRINCE project (2016-2019) which led to the first official consumption-based accounts in Sweden. In the project NTNU IndEcol developed and implemented the coupled model approach (Open-source repository of the project at:

https://github.com/rich-wood/hySNAC). A follow up project (PRINCE II - sub-contracted to Vector Sustainability by Swedish Statistics) fully operationalised the concept for Swedish Statistics, which now regularly uses the model to publish consumption-based accounts.

A similar approach was then applied by the Danish Energy Agency (DEA, 2019-2023), where consumption-based carbon accounts for Denmark were produced. This was a sub-contract with NIRAS A/S initially. A follow-up contract was established between DEA and Vector Sustainability to institutionalise the approach. The follow-up work also involved the implementation of a scenario-based version to look at future scenarios of consumption-based emissions.

The Norwegian Department of Public Procurement (DFØ) also used the coupled model approach to calculate the second version of the Norwegian specific footprint intensities for public procurement. This was a sub-contract with NIRAS A/S and produced Scope 1, 2 and 3 carbon intensities for the purchase of good and services to bused for assessing public procurement. This was the first coupled model implemented for Norwegian data. The model was extended to include the endogenization of capital goods.

Recently, the CaFEAN (Carbon Footprint of the Economic Activity of Norway) project calculated the official Norwegian consumption based accounts based on coupling EXIOBASE with the official Norwegian greenhouse-gas and economic statistics (from SSB). The project developed by Vector Sustainability, XIO Sustainability Analytics for Miljødirektoratet. The report was published in January 2024 (see below).

The European Environment Agency uses EXIOBASE for multiple reports (https://www.eea.europa.eu/en/advanced-search?q=exiobase) and also lists it at one of their main data sources.

Commercial/Enterprise use:

The EXIOBASE database allows the calculation of Scope 1, 2, and 3 GHG emission factors, covering 200 commodities and 163 industries for all major economies. EXIOBASE data is openly available, and we do not track/register individual users. However, over 50,000 downloads on Zenodo (https://doi.org/10.5281/zenodo.5589597) suggest a wide spread use of the database. Some known users of EXIOBASE are listed below.

Ducky: Norwegian company which provides software solutions to track, reduce and report your climate efforts - provides GHG reporting for enterprises and publics sector. EXIOBASE is listed in their data source: https://www.ducky.eco/our-data

Climatiq: A data provider for embed GHG data. EXIOBASE is one of their featured data sources for global emission factors: https://www.climatiq.io/data/source/exiobase

Connect.earth: Carbon data for Sustainable Finance. EXIOBASE is listed as one of their data sources: https://connect.earth/faqs/ - "Where do you get the data from?"

Bioscope: Biodiversity Input-Output for Supply Chain & Operations Evaluation. Uses EXIOBASE in connection with the ReCiPe Impact Assessment factors for calculating biodiversity impacts. https://bioscope.info

5. Sources to corroborate the impact

Swedish Consumption Accounts/PRINCE project

Viveka Palm (now at Eurostat) viveka.palm@scb.se / Viveka.PALM@ec.europa.eu +352-4301-33244
Nils Brown (Statistics Sweden - SCB) nils.brown@scb.se +46 10-479 40 26 | +46 72-084 40 26

https://www.scb.se/en/finding-statistics/statistics-by-subject-area/environment/environmental-accounts-and-sustainable-development/system-of-environmental-and-economic-accounts/pong/statistical-news/environmental-accounts--environmental-pressure-from-consumption-2020/

Danish Energy Agency

Kristian Voss Olesen, Centre for Systems Analysis, +45 33 95 09 90, krvo@ens.dk

Norwegian Department of Public Procurement (DFØ) project:

Jonas Karstensen Jonas.Karstensen@dfo.no; +47 934 41 796

CaFEAN: Carbon Footprint of the Economic Activity of Norway

https://www.miljodirektoratet.no/aktuelt/fagmeldinger/2024/januar-2024/utslipp-av-klimagasser-fra-norsk-forbruk-er-beregnet/

https://www.miljodirektoratet.no/publikasjoner/2024/januar-2024/cafean-carbon-footprint-of-the-economic-activity-of-norway/

Contakt: Nina Holmengen seksjonsleder Nina.Holmengen@miljodir.no

NTNU, EPT, Impact case number 3

Institution: Norwegian University of Science and Technology (NTNU)
Administrative unit: Department of Energy and Process Engineering (EPT)
Title of case study: FME **HighEFF** - Center for Environment Friendly Energy Research
Period when the underpinning research was undertaken: 01.01.2017 - 31.12.2022
Period when staff involved in the underpinning research were employed by the submitting institution: 01.01.2017 - 31.12.2022
Period when the impact occurred: 01.01.2017 - 31.12.2022

1. Summary of the impact

This case study is related to a large Center of Environment Friendly Energy Research (HighEFF) with 34 partners (15 industrial end users, 9 vendors, 2 research institutes and 8 universities). As a result, it is difficult to follow the template in a strict way. SINTEF Energy Research has been the program leader, while NTNU heavily represented by the PnP research group has been the main academic partner. The overall **Goals** of HighEFF have been (a) reduced greenhouse gas emissions, (b) reduced specific energy consumption, and (c) increased value creation. These KPIs are achieved by improving energy efficiency at different levels of industrial processes from individual pieces of equipment to industrial sites/parks. The **Vision** of HighEFF has been to make Norwegian industry the world's greenest. With international partners, the impact from the research goes beyond national boarders. **Energy efficiency** is often ranked first in the mitigation of climate change since (i) the cleanest energy is the one that is not used, (ii) actions can start now without further delay, and (iii) such projects may even create profit.

2. **Underpinning research**

The research in HighEFF is spanning from development of new **equipment** for Heat Engines, Heat Pumps and Refrigeration Cycles to developing new tools and **methodologies** for analyzing, designing and optimizing industrial processes and energy plants. Examples include natural working fluids for heat pumps and refrigeration cycles, new compressor concepts for High Temperature Heat Pumps, new bottoming cycles for offshore oil & gas platform processes, and new methodologies for simultaneous Work and Heat Integration. **Four professors** in the PnP research group have been active in the entire HighEFF period in line with the reporting period (2017-2022), and the numbers listed in the following are all related to HighEFF research: Trygve M Eikevik: 2 PhDs, 32 publications (12 with Armin Hafner). Armin Hafner: 2 PhDs, 68 publications (12 with Trygve Eikevik). Lars O. Nord: 2 Post.docs, 15 publications. Truls Gundersen: 2 PhDs, 2 Post.docs, 53 publications. In total, the PnP research group has supervised **6 PhDs**, **4 Post.docs** and published **156 journal papers**. The total numbers for HighEFF are 19 PhDs, 6 Post.docs and 333 journal papers. In addition, the mentioned professors have supervised 7 (of a total of 11) "associated" PhDs, i.e. PhDs doing HighEFF relevant research without being funded by HighEFF. Two international PhDs, one at MIT in the US and one at University of Manchester in the UK, have been co-supervised by Truls Gundersen. Trygve Eikevik has 10 **joint publications** with Shanghai Jiao Tong University and Truls Gundersen has 16 joint publications with MIT. The PhDs and Post.docs belonging to the PnP research group has achieved 3 **Awards**: (1) Best Paper Award, ESCAPE'28 in 2018 (of 250 papers), (2) Best Review Paper Award from the journal Processes in 2020, and (3) 2nd Best Young Speaker Award, PRES'20 in 2020. Beyond PhD supervision, the PnP group has also been very active in the **scientific administration** of HighEFF. Truls Gundersen has been Scientific Leader of the entire HighEFF center and also NTNU coordinator and responsible for the collaboration with MIT and University of Manchester. Armin Hafner has been Research Area

leader for RA-2 on Components. Trygve Eikevik has been Work Package leader for WP-2.3 on Natural Working Fluids. HighEFF is a truly **International** Center, with PhDs/Post.docs from 15 countries and universities spread around the world (2 in the US, 1 in UK, 1 in Japan, 1 in China, 1 in Sweden and 2 in Norway). These international aspects are also represented by the industrial companies and the vendors.

3. References to the research

Nami H, Ertesvåg IE, Agromayor R, Riboldi L, **Nord LO**. Gas turbine exhaust gas heat recovery by organic Rankine cycles (ORC) for offshore combined heat and power applications - Energy and exergy analysis. *Energy*, 165(B):1060-1071, 2018, https://doi.org/10.1016/j.energy.2018.10.034, **91** Scopus citations.

Gullo P, **Hafner A**, Banasiak K. Transcritical R744 refrigeration systems for supermarket applications: Current status and future perspectives. *International Journal of Refrigeration*, 93:269-310, 2018, https://doi.org/10.1016/j.ijrefrig.2018.07.001, **142** Scopus citations.

Selvnes H, Allouche Y, Manescu RI, **Hafner A**. Review on cold thermal energy storage applied to refrigeration systems using phase change materials. *Thermal Science and Engineering Progress*, 22:100807, 2021, https://doi.org/10.1016/j.tsep.2020.100807, **97** Scopus citations.

Palacz M, Smolka J, Kus W, Fic A, Bulinski Z, Novak AJ, Banasiak K, **Hafner A**. CFD-based shape optimization of a CO_2 two-phase ejector mixing section. *Applied Thermal Engineering*, 95:62-69, 2016, https://doi.org/10.1016/j.applthermaleng.2015.11.012, **94** Scopus citations.

Bamigbetan O, **Eikevik TM**, Nekså P, Bantle M. Review of vapour compression heat pumps for high temperature heating using natural working fluids. *International Journal of Refrigeration*, 80:197-211, 2017, https://doi.org/10.1016/j.ijrefrig.2017.04.021, **132** Scopus citations.

Haida M, Banasiak K, Smolka J, **Hafner A**, **Eikevik TM**. *International Journal of Refrigeration*, 64:93-107, 2016, https://doi.org/10.1016/j.ijrefrig.2016.01.017, **83** Scopus citations.

Subramanian ASR, **Gundersen T**, Adams II TA. Modeling and simulation of energy systems: A review. *Processes*, 6(12):238, 2018, https://doi.org/10.3390/pr6120238, **94** Scopus citations.

Yu H, Kim D, **Gundersen T**. A study of working fluids for Organic Rankinne Cycles (ORCs) operating across and below ambient temperature to utilize Liquefied Natural Gas (LNG) cold energy. *Energy*, 167:730-739, 2019, https://doi.org/10.1016/j.energy.2018.11.021, **80** Scopus citations.

Publication Awards:

Yu H, Vikse M, **Gundersen T**. Comparison of reformulations of the Duran-Grossmann model for Work and Heat Exchange Network (WHEN) synthesis. *Computer Aided Chemical Engineering*, 43:489-494, 2018, https://doi.org/10.1016/B978-0-444-64235-6.50087-5. Best Conference Paper (of 250) at ESCAPE'28, Graz, Austria, 2018.

Subramanian ASR, **Gundersen T**, Adams II TA. Modeling and simulation of energy systems: A review. *Processes*, 6(12):238, 2018, https://doi.org/10.3390/pr6120238, **Received Best Review Paper Award** from journal, 2018.

Zotica C, **Nord LO**, Kovacs J, Skogestad S. Optimal operation of heat to power cycles: A new perspective using a systematic plantwide control approach. *Computer Aided Chemical Engineering*, 46:1429-1434, 2019, https://doi.org/10.1016/B978-0-12-818634-3.50239-3. Best paper award at ESCAPE'29, Eindhoven, the Netherlands, 2019.

4. Details of the impact

For such a large Research Center as HighEFF represents, it is extremely difficult to quantify and even exemplify how new insights and developments from research have impacted industry and society. Up front, important results are 25 highly qualified PhDs/Post.docs (10 in the PnP research group) that have been recruited by industry, research institutes and universities. The impact of 333 journal publications (156 in the PnP research group) is of course significant although hard to quantify. The large number of journal publications is also an indication that it is very hard to pin-point individual research results and insights that impact industrial processes.

At the start of the program, it was stated that HighEFF should contribute to **10%** reduction in greenhouse gas emissions, **30%** reduction in specific energy consumption and (unspecified) increased value creation. Research Area 6 on Industrial Case Studies have reported the outcome of a number of projects with industry involved (see link to an overview of HighEFF projects in Section 5). The industrial partners of HighEFF have been dividedd into the following 4 sectors: (1) Oil, Gas and Energy, (2) Metal and Material, (3) Industry Clusters and (4) Food and Chemical. Accumulated, these Case Studies have reported **4%** reduction in GHG emissions (ranging from 3% for Metals and Material to 22% for Food and Chemical) and 9% reduction in specific energy consumption (ranging from 8% in Oil, Gas and Energy to 16% in Food and Chemical). Even though these percentages may seem to be low, they relate to very large numbers in GHG emissions and energy consumption.

On the research topic of new bottoming cycles for offshore oil & gas platform processes, the research has led to industrial development and plans for upgrades to existing offshore installations and included in new installations, with expected CO_2 emission reductions of 9-25% depending on the case studied (refer to the three references from Nord et al. in Section 5). Note that this research topic was started prior to the FME HighEFF case study and has generated multiple spin-off projects and direct-financed industrial projects. The more applied and industry-close R&D have involved other research insitutions, most notably SINTEF Energy Research. The latest optimized designs are currently under industrial development and has to date not been installed on an oil and gas platform. The time from idea to an actual installation in the conservative oil & gas industry is long. The research underpinned the impact by applying methods of process design, modeling, simulation and optimization to arrive at improved and new designs for offshore bottoming cycles (leading to a combined cycle with the gas turbine as topping cycle) with improved thermal efficiencies and consequently lowered CO_2 emissions per generated kWh of power. The process went from academic research via applied industry-close R&D to industrial development involving both academic partners, research insitutions, end-users, engineering & consulting companies and vendors.

5. Sources to corroborate the impact

Overview of HighEFF Projects with industrial impact:
https://www.sintef.no/projectweb/higheff/outreach/

Nord LO, Bolland O. Design and off-design simulations of combined cycles for offshore oil and gas installations. Applied Thermal Engineering, 54 (1):85-91, 2013. **42** Scopus citations .
https://doi.org/10.1016/j.applthermaleng.2013.01.022

Nord LO, Martelli E, Bolland O. Weight and power optimization of steam bottoming cycle for offshore oil and gas installations. *Energy*, 76:891-898, 2014. **32** Scopus citations. https://doi.org/10.1016/j.energy.2014.08.090

Riboldi L, **Nord LO.** Lifetime assessment of combined cycles for cogeneration of power and heat in offshore oil and gas installations. *Energies*, 10 (6), art. no. 744, 2017. **24** Scopus citations. https://doi.org/10.3390/en10060744

NTNU, EPT, IMPACT CASE 4

Institution: NTNU
Administrative unit: Department of Energy and Process Engineering, EPT
Title of case study: High Head Francis Turbines (HiFrancis-project)
Period when the underpinning research was undertaken: 2016 - 2019
Period when staff involved in the underpinning research were employed by the submitting institution: 2016 - 2019
Period when the impact occurred: 2019 and onwards

1. Summary of the impact

In the HiFrancis project, extensive measurements and experiments was carried out to understand the physics of turbine impellers. The results are used to develop simulation methods and validated procedures that the turbine manufacturers can apply when new turbines are designed. The research has brought knowledge to the hydropower industry about the physics of the resonance phenomena in the turbine impellers of Francis hydropower turbines. This has brought the probability of breakdown from 10% to 5% for new turbines. The value of the reduced risk on a worldwide basis is calculated to NOK 5 Billion.

2. Underpinning research

The average age of Norwegian hydro power plants are more than 50 years, and many show sign of fatigue and needs to be constantly maintained or refurbished. Additionally, some power plants in Norway have experienced failures when installing new Francis turbines. The main problem is the formation of cracks in the turbine runner originating from high pressure amplitudes and/or resonance. The Norwegian hydropower industry have therefore addressed the risk of failure as a problem and want to see that the turbine manufacturers are capable of delivering turbines without formation of cracks before the end of the lifetime. Altogether, 9 utility companies, 4 turbine manufacturers, 3 consultants, Energi Norge, and NTNU are partners in this project.

The main challenge for the project was to carry out model turbine measurements, which can be utilized to build a procedure for the numerical analysis of the Fluid-Structure Interaction (FSI) on high head Francis turbines. This procedure reduced the risk for resonance and breakdown in future installation of high head turbines.

The project worked with simplified models for the turbine runner and a complete Francis turbine model, and thorough measurements combined with FSI-analysis was carried out. The flow conditions in a Francis turbine runner will be simplified and isolated in a blade cascade and the material properties such as the natural frequency of the runner was tested with simplified geometry. The model of the Francis turbines at the Tokke power plant was utilized for the measurements. Here, steady state and transient operation of the turbine will be investigated. The main challenge was to carry out good measurements of the pressure and stress/strain in the turbine runner. The measurements from the Tokke model turbine were provided to other researchers through the Francis-99 workshops. The Francis-99 workshops aim to determine the state of the art of high head Francis turbine numerical simulations (flow and structure) under steady and transient operating conditions as well as promote their development and knowledge dissemination openly. More information is given on the website: www.ntnu.edu/nvks/hifrancis

Names of the key researchers and what positions they held at the administrative unit at the time of the research:

- Ole Gunnar Dahlhaug, Professor (project manager/ principal investigator)
- Pål-Tore Selbo Storli, Associate Professor
- Chirag Trivedi, PostDoc

- Bjørn Winther Solemslie, PostDoc
- Einar Agnalt, PhD-student
- Kristian Sagmo, PhD-student
- Carl Werdelin Beargan, PhD-student
- Erik Os Tengs, PhD-student
- Petter T. Haug Østby, PhD-student

3. References to the research

The project has produced 38 publications and all of them can be seen from this link: https://www.ntnu.edu/nvks/publications#/view/publications

Reference 1:
- Authors: Einar Agnalt, Igor Iliev, Bjørn Winther Solemslie, Ole Gunnar Dahlhaug
- Title: *On the Rotor Stator Interaction Effects of Low Specific Speed Francis Turbines*
- Year of publication: 2019
- DOI: 10.1155/2019/5375149
- https://www.scopus.com/record/display.uri?origin=resultslist&eid=2-s2.0-85063232708

Reference 2:
- Authors: Chirag Trivedi, Einar Agnalt, Ole Gunnar Dahlhaug
- Title: *Experimental study of a Francis turbine under variable-speed and discharge conditions*
- Year of publication: 2018
- DOI: 10.1016/j.renene.2017.12.040
- https://www.scopus.com/record/display.uri?origin=resultslist&eid=2-s2.0-85037972172

Reference 3:
- Authors: Ken-Robert G. Jakobsen, Erik Os Tengs, Martin Aa. Holst
- Title: *Reducing computational effort of high head Francis turbines*
- Year of publication: 2019
- DOI: 10.1088/1755-1315/240/7/072001
- https://www.scopus.com/record/display.uri?origin=resultslist&eid=2-s2.0-85063931411

Reference 4:
- Authors: Ken-Robert G. Jakobsen, Erik Os Tengs, Martin Aa. Holst
- Title: *Model order reduction technique applied on harmonic analysis of a submerged vibrating blade*
- Year of publication: 2019
- DOI: 10.2478/ijame-2019-0009
- https://www.scopus.com/record/display.uri?origin=resultslist&eid=2-s2.0-85064267861

Reference 5:
- Authors: Einar Agnalt, Petter T. Haug Østby, Bjørn Winther Solemslie, Ole Gunnar Dahlhaug
- Title: *Experimental study of a low-specific speed francis model runner during resonance*
- Year of publication: 2018
- DOI: 10.1155/2018/5796875
- https://www.scopus.com/record/display.uri?origin=resultslist&eid=2-s2.0-85059944204

Reference 6:
- Authors: Bjørn Winther Solemslie, Chirag Trivedi, Einar Agnalt, Ole Gunnar Dahlhaug
- Title: *Pressure pulsations and fatigue loads in high head Francis turbines*
- Year of publication: 2019
- DOI: 10.1088/1755-1315/240/2/022039
- https://www.scopus.com/record/display.uri?origin=resultslist&eid=2-s2.0-85063882339

All outputs cited in this section must be capable of being made available to panels. If they are not available in the public domain, the administrative unit must be able to provide them if requested by RCN or the evaluation secretariate.

4. Details of the impact

The research within this project has brought knowledge to the hydropower industry about the physics of the resonance phenomena in the turbine impellers of Francis hydropower turbines. This has brought the probability of breakdown from 10% to 5% for new turbines. During the impact study made by Impello Management as in 2018, the value of the reduced risk on a worldwide basis was calculated to NOK 5 billion. Statkraft has estimated the value creation from the HiFrancis project to NOK 84 million. This value creation is from the refurbishment of Kvilldal and Rana Hydro Power Plants in 2018 and 2019.
The dissemination of the results has been through scientific publications and *recommended practice.* The most effective dissemination has been the implementation of the *recommended practice* by the consultancies that work with the hydropower industry.

5. Sources to corroborate the impact

Statkraft was a partner I the project and they was the first power company to utilize the results from the HiFrancis project. Contact person at Statkraft is Jan Petter Haugli, E-mail: Jan.Petter.Haugli@statkraft.com

Impello Management as carried out a study about the outcomes from the energy related research in Norway. (Effekter av energiforskningen) The report from this study was published 28th December 2018. Today, Impello Management as is owned and operated by the company Azets Consulting, which can be contacted through their webpage: www.azetsconsulting.no

Norwegian University of Science and Technology, Department of Architecture and Technology – Case 1

Institution: Norwegian University of Science and Technology
Administrative unit: Department of Architecture and Technology
Title of case study: Zero Emission Buildings Definition and Related Applications
Period when the underpinning research was undertaken: 2009-2016 (reporting in 2014 and 2016)
Period when staff involved in the underpinning research were employed by the submitting institution: 2009 - 2016
Period when the impact occurred: From 2012 and onwards.

1. Summary of the impact (indicative maximum 100 words).

The Zero Emission Buildings (ZEB) definition, developed at NTNU in collaboration with SINTEF Community and ZEB Centre partners, has significantly influenced the EU's energy efficiency strategies. It considers emissions from all life cycles of the building process, including operational and embodied carbon emissions. The ZEB definition aligns with the EU's 20-20-20 targets, emphasizing the importance of whole-life carbon (WLC) assessments for reducing a building's carbon footprint. The structure of a Whole Life-Cycle Carbon assessment is defined by BS EN 15978:2011, contributing to a more holistic understanding of a building's environmental impact. The ZEB definition also includes the concept of the "nearly Zero Energy Building" (nZEB), emphasizing energy efficiency, environmental impact, and life-cycle cost.

2. Underpinning research (indicative maximum 500 words)

The Zero Emission Buildings (ZEB) project hosted by the Norwegian University of Science and Technology (NTNU) was an eight-year research initiative from 2009 to 2016, led by a team of dedicated researchers. The project's primary focus was on emissions related to all life cycles of the building process, including operational carbon emissions from daily energy use and embodied carbon emissions from stages such as material sourcing, component fabrication, transport, construction, maintenance, repair, replacement, demolition, dismantling, and disposal.

The Zero Emission Buildings (ZEB) project at the Norwegian University of Science and Technology (NTNU) was a comprehensive research initiative that spanned eight years, from 2009 to 2016. The project was led by a team of dedicated researchers at NTNU and SINTEF Community and conducted in close collaboration with almost 30 industry partners. There are several contributors to the definition, including Inger Andresen, Tor Helge Dokka (Skanska/SINTEF Community), Arild Gustavsen, Anne Grete Hestnes, Aoife Houlihan Wiberg, Laurent Georges, Thorildur Kristjansdottir, Thomas Berker, Hans Martin Mathisen, Ruth Woods, (NTNU), Igor Sartori, Marianne Wiik, Birgit Risholt, Terje Jacobsen, Ann Kristin Kvellheim, and Berit Time (SINTEF Community).

The ZEB project developed a definition for zero-emission buildings that has profoundly influenced the design of energy-efficient buildings and the integration of renewable energy technologies. This definition, which is now a prominent feature in EU strategy documents (*Maduta, C., Melica, G., D`agostino, D. and Bertoldi, P., Defining zero-emission buildings, EUR 31382 EN, Publications Office of the European Union, Luxembourg, 2023, ISBN 978-92-76-61615-3, doi:10.2760/107493, JRC129612*), aligns with the EU's 20-20-20 targets, emphasizing the reduction of emissions.

The project's research also led to a deeper understanding of how energy-efficient buildings interact with the power grid, focusing on the efficient distribution and use of renewable energy, thereby reducing emissions.

Broadening the scope from the zero emission building (ZEB), the goal of the zero emission neighbourhood (ZEN) is to bring the zero emission concept to a neighbourhood scale. Based on experiences with ZEB and ZEN, a mapping review has been conducted to analyse how parametric life cycle assessment (LCA) and algorithms have been used to address neighbourhoods, buildings, and construction materials. This study fostered the development of algorithmic approaches to improve the ZEB tool as a decision-support tool.

The project's legacy continues to influence current research and practice in the field of sustainable architecture and urban planning, demonstrating the enduring impact of the ZEB project and its significant contribution to the fight against climate change by reducing emissions. The research insights from the ZEB project have been embodied in several project reports and journal articles that discuss the definition of Zero Emission Buildings (ZEB) and the associated calculation methodologies.

3. References to the research (indicative maximum of six references)

This section should provide references to key outputs from the research described in the previous section, and evidence about the quality of the research. All forms of output cited as underpinning research will be considered equitably, with no distinction being made between the types of output referenced. Include the following details for each cited output:

Gustavsen, A., Jacobsen, T. and Andresen, I., 2016. Norway demonstrates zero emission buildings. *IEA EBC News*, (63).

Kristjansdottir, T., Fjeldheim, H., Selvig, E., Risholt, B., Time, B., Georges, L., Dokka, T.H., Bourelle, J., Bohne, R.B. and Cervenka, Z., 2014. *A Norwegian ZEB-definition - embodied emission*. ZEB Project reports, ISBN: 978-82-536-1398-7.

Andresen, Inger; Wiik, Marianne Rose Kjendseth; Fufa, Selamawit Mamo; Gustavsen, Arild. (2019) The Norwegian ZEB definition and lessons learnt from nine pilot zero emission building projects. IOP Conf. Ser.: Earth Environ. Sci. 1078 012047 DOI 10.1088/1755-1315/1078/1/012047.

Wiik, M.R.K.; Selvig, E.; Fuglseth, M.S.; Lausselet, C.; Resch, E.; Andresen, I. (2020) GHG emission requirements and benchmark values in Norwegian building codes. OP Conf. Ser.: Earth Environ. Sci. 588 022005 DOI 10.1088/1755-1315/588/2/022005

Resch, E., Lausselet, C., Brattebø, H., Andresen, I. (2019) An analytical method for evaluating and visualizing embodied carbon emissions of buildings, *Building and Environment*, Volume 168, 2020, 106476, ISSN 0360-1323, https://doi.org/10.1016/j.buildenv.2019.106476.

Kristjansdottir, T.F.; Wiberg, A.A.M.H.; Andresen, I.; Georges, L.; Heeren, N.; Good, C. (2018) Is a net life cycle balance for energy and materials achievable for a zero-emission single-family building in Norway?, *Energy and Buildings*, Volume 168, 2018, Pages 457-469, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2018.02.046.

Andresen, I. (2017) Towards Zero Energy and Zero Emission Buildings – Definitions, Concepts and Strategies. Curr Sustainable Renewable Energy Rep 4, 63–71 (2017). https://doi.org/10.1007/s40518-017-0066-4

4. Details of the impact (indicative maximum 750 words)

The Zero Emission Buildings (ZEB) project hosted by the Norwegian University of Science and Technology (NTNU), lead together with SINTEF Community and carried out together with ZEB Centre partners, has made significant contributions to the field of sustainable architecture and energy-efficient building design. The research conducted under this project has underpinned the development and implementation of zero-emission building concepts, not only in Norway but also in other parts of the world.

The ZEB project's research has been instrumental in defining what constitutes a Zero Emission Building. Through a series of publications and reports, the project has provided clear guidelines and methodologies for achieving zero emissions in buildings. This research has been disseminated through academic journals, conferences, and public outreach programs, influencing a wide range of stakeholders, including architects, engineers, policymakers, and the general public.

The research conducted by the ZEB project was part of a broader body of work on sustainable architecture and energy efficiency. The project collaborated with other research institutions and industry partners, contributing specific expertise on zero-emission building concepts. For instance, the project's work on embodied emissions has been particularly influential, providing a comprehensive framework for assessing the environmental impact of building materials and construction processes.

The beneficiaries of the ZEB project's research are manifold. The architectural and engineering communities have gained valuable insights into the design and construction of zero-emission buildings. Policymakers have been provided with evidence-based recommendations for promoting sustainable building practices. The general public, as end-users of these buildings, benefit from reduced energy costs and a healthier living environment.

The impact of the ZEB project's research is evident in the increasing adoption of zero-emission building concepts in Norway and beyond. Several buildings constructed based on the ZEB project's guidelines have achieved zero emissions, demonstrating the feasibility and benefits of this approach. These include the Powerhouse Kjørbo office building, which has been extensively studied and documented by the ZEB project.

The ZEB project's research has also influenced policy development. The Norwegian government has incorporated zero-emission building concepts into its building standards, codes and regulations, reflecting the impact of the ZEB project's research.

The ZEB project was initiated in 2009, and its impacts have been unfolding over the past decade. The project's influence continues to grow as more and more buildings are designed and constructed based on its research findings.

In conclusion, the ZEB project at NTNU has made a distinct and material contribution to the advancement of zero-emission building concepts. Its research has underpinned significant impacts in the fields of sustainable architecture and energy-efficient building design, benefiting a wide range of stakeholders and contributing to the global effort to combat climate change.

To further elaborate on the impact of the ZEB project, it's important to note that the project's research has not only influenced the design and construction of individual buildings but also the planning and development of entire communities. The concept of a zero-emission neighborhood or district, where all buildings collectively achieve zero emissions, is a direct extension of the ZEB

project's research. This holistic approach to sustainable urban development, considering not only individual buildings but also the interconnections between them, represents a significant shift in how we think about and plan our cities.

Moreover, the ZEB project's research has contributed to the development of new technologies and solutions for energy-efficient building design. These include advanced materials and construction techniques, innovative energy supply systems, and smart technologies for energy management and control.

5. Sources to corroborate the impact (indicative maximum of ten references)

Effekter av energiforskningen, Hovedrapport, Impello Management AS Trondheim, 28. desember 2018, https://mozees.no/wp-content/uploads/2019/05/2018-Hovedrapport-effektstudie-Impello-Menon.pdf.

NS 3720:2018 Norwegian Standard: Method for Greenhouse Gas Calculations for Buildings. Standards Norway, https://online.standard.no/nb/ns-3720-2018

Byggteknisk forskrift, § 17-1. Klimagassregnskap fra materialer (Building code requirements for calculation of greenhouse gas emissions in buildings). https://www.dibk.no/regelverk/byggteknisk-forskrift-tek17/17/17-1, DiBK, Norwegian Directorate for Building Quality.

Norwegian University of Science and Technology, Department of Architecture and Technology – Case 2

Institution: Norwegian University of Science and Technology (NTNU)
Administrative unit: Department of Architecture and Technology
Title of case study: Daylighting solutions and systems for retrofitting buildings in the Nordic climate to low energy, 0-energy or ZEB standard
Period when the underpinning research was undertaken: 2013
Period when staff involved in the underpinning research were employed by the submitting institution: 2013
Period when the impact occurred: 2013-2016

1. Summary of the impact (indicative maximum 100 words)

The "DayLighting" project aimed to enhance the utilization of natural light in buildings, particularly those transitioning to low-energy or zero-energy standards. The project's impact was twofold. Firstly, it contributed to reducing energy consumption and CO2 emissions, addressing the urgent need for climate action. Secondly, it improved the indoor environment and in particular daylight conditions in buildings.

2. Underpinning research (indicative maximum 500 words)

The "DayLighting" project, carried out from mid-2013 to mid-2016, was a comprehensive study aimed at enhancing the utilization of natural light in buildings, particularly those transitioning to low-energy or zero-energy standards. The research was led by Professor Barbara Matusiak at the Department of Architecture and Technology, NTNU, in collaboration with the ZEB Research Community at NTNU/SINTEF, Link Arkitektur, and Glass og Fasadeforening.

The research insights and findings that underpinned the impact claimed in the case study were multifaceted. The project identified a clear contradiction between compact building shape and good daylighting, with no clear guidance for stakeholders about the reasonable limits of compactness. It was found that the transformation of a building to a low-energy standard often negatively impacts the daylighting level in interiors. The project highlighted an acute need for knowledge in the field of daylighting, especially in low-energy/0-energy buildings and called for the development of new solutions and methods for better utilization of natural light in coherence with electrical light.

The underpinning research produced by the submitted unit was extensive and involved several key tasks. The first task involved a comprehensive review of the latest products in the category of daylighting systems and products. The aim was to develop a deep understanding of the optical qualities, light, and energy efficiency of these systems and products, including those with integrated electrical light sources.

The second task involved the careful evaluation and calibration of evaluation tools, including simulation programs, scale-studies in Daylight Lab, and full-scale measurements. The calibration was made against scale-model measurements in Daylight Lab. The comparison between Daylight Factor (D) and Median Daylight Illuminance (MDI) for Norwegian climate was also done.

The third task involved the analysis of real buildings, which often represent a large group of buildings with similar parameters. The analysis of case-buildings provided valuable insights into the challenges and opportunities for daylighting in such buildings.

The fourth task involved the development and testing of new daylighting strategies and solutions. The new ideas were tested at scale-models in Daylight laboratory, simulated with advanced lighting-simulation programs (Radiance, Relux), and even in real case buildings.

The final task involved the development of daylighting guidance for stakeholders who plan on upgrading buildings to low-energy, 0-energy, or ZEB standard. The guidance was written in a user-friendly format and disseminated widely to ensure maximum impact.

The project was carried out in close cooperation with the international research community participating in the IEA Task 50 Advanced Lighting Solutions for Retrofitting Buildings. The project was also linked to the ZEBUP project proposed by the SINTEF/NTNU researchers who are strongly connected to the ZEB Centre.

In conclusion, the "DayLighting" project made significant strides in addressing the challenges of sustainable and energy-efficient buildings. The research insights and findings have paved the way for better natural daylight solutions in highly energy efficient buildings.

The "DayLighting" project was led by key researchers at the Norwegian University of Science and Technology (NTNU) and SINTEF.

Professor Barbara Matusiak was the project leader. She held a position at the Faculty of Architecture, NTNU, and led the Light & Colour Group. Her expertise in architectural lighting and colour played a crucial role in the project. She joined NTNU in 2001 and has been a part of the faculty since then.

The project also involved researchers from the ZEB research community at NTNU/SINTEF. The Zero Emission Buildings (ZEB) research community is a leading group in the field of sustainable and energy-efficient buildings. The exact dates of their involvement in the project are not specified, but they were integral to the project throughout its duration.

The project also collaborated with **Link Arkitektur**, a leading architectural company in Norway, and **Glass og Fasadeforening**, an association of diverse companies producing and supplying glazed facades, windows, etc.

The research was conducted in the context of a growing global emphasis on sustainable and energy-efficient buildings. Buildings account for approximately 40% of total energy consumption and emissions, making the building sector a key area for climate action. The project was particularly relevant for the Nordic climate, where the utilization of natural light presents unique challenges and opportunities.

3. References to the research (indicative maximum of six references)

1. Matusiak, Barbara. (2012). "Low-energy house, back to the 'arestue': a thought experiment about low-energy houses." *Architectural Science Review*, Volume 55, Issue 2, pp. 86-91. DOI: 10.1080/00038628.2012.693813
2. The Research Centre on Zero Emission Buildings. (2009 – 2016). "The Research Centre on Zero Emission Buildings." *ZEB Centre*. URL: www.zeb.no
3. International Energy Agency. (2008). "IEA Task 40/Annex 52, Towards Net Zero Energy Solar Buildings." *IEA SHC Task 40 and ECBCS Annex 52*. URL: http://task40.iea-shc.org/
4. International Energy Agency. (2012). "IEA Task 50 "Advanced Lighting Solutions for Retrofitting Buildings." *IEA Task 50*. URL: http://task50.iea-shc.org/

5. NTNU-seminar (2015) “Computer simulations vs scale model studies” IBAN: 978-82-7551-110-0
6. Matusiak, Barbara. (2015) “Daylighting is More than an Energy Saving Issue” IntechOpen, book chapter in: Energy Efficient Buildings DOI: 10.5772/65866

4. Details of the impact (indicative maximum 750 words)

The “DayLighting” project, conducted from mid-2013 to mid-2016, made a distinct and material contribution to the field of sustainable and energy-efficient buildings. The research underpinned significant advancements in the utilization of natural light in buildings, particularly those transitioning to low-energy or zero-energy standards.

The research was disseminated through various channels, including international scientific journals, professional magazines, popular science articles, and courses arranged by Lyskultur. The project’s findings were also incorporated into teaching material at NTNU, thereby influencing the next generation of architects and engineers.

A daylight seminar was arranged at NTNU in October 2015 for project participants, students and the public. After a few presentations seminar participants could visit one of the studios at NTNU-campus where six existing skylights have been replaced by new ones designed according to the results of the theoretical investigation from the project. The visual comfort, energy consumption for lighting and the overall perception of the room were greatly improved in this full-scale project. Students having their working places (long-term experience) in the room still express great appreciation for the solution.

The research conducted by the submitted administrative unit, the Faculty of Architecture at NTNU, was part of a wider body of research that contributed to the impact. The project was carried out in close cooperation with the ZEB research community at NTNU/SINTEF, Link Arkitektur, and Glass og Fasadeforening. The contribution of the submitted administrative unit’s research was the development of daylighting guidance for stakeholders who plan on upgrading buildings to low-energy, 0-energy, or ZEB standard. This guidance was written in a user-friendly format and disseminated widely to ensure maximum impact. Additionally, a series of popular scientific articles was published in the “Lyskultur”, the only Norwegian professional lighting journal.

The beneficiaries of the research are manifold. They include building owners, architects, and engineers who plan on upgrading buildings to low-energy, 0-energy, or ZEB standard. The research has also benefitted the glass and façade industry, as well as the lighting industry, by providing new research findings necessary for the development of new products. Furthermore, the research has benefitted users of buildings that are to be retrofitted to the low-energy standard, as it has led to better strategies and solutions for daylighting in such buildings.

The nature of the impact is significant. By improving the indoor environment in buildings, particularly in terms of daylighting, the research enhances the conditions for the building users.

Evidence of the extent of the impact can be seen in the wide adoption of the project’s findings and developments in the building sector. The project’s guidance on daylighting has been widely disseminated and used by stakeholders planning to upgrade buildings to low-energy, 0-energy, or ZEB standards. Furthermore, the project’s findings have contributed to the global discourse on sustainable building practices and have paved the way for better daylighting solutions in well-insulated and energy efficient buildings.

5. Sources to corroborate the impact (indicative maximum of ten references)

1. Development of new ideas for daylighting solutions for windows and skylights
- Paola Jara Cerda, Barbara Matusiak "Toward new design of laser cut panels for scattering of sunlight at high latitudes" July 2017, Conference paper: PLEA 2017
- Andreas Weibe, Barbara Matusiak, "Towards New Design of Laser Cut Acrylic Panels for Windows" January (2019) Journal of Daylighting 6(1):1-10 DOI: 10.15627/jd.2019.1
- Farimah Piraei, Barbara Matusiak, Valerio Roberto Maria Lo Verso "Evaluation and Optimization of Daylighting in Heritage Buildings: A Case-Study at High Latitudes" Buildings (2022) DOI: 10.3390/buildings12122045

2. The necessity for better integration of electric light with daylight was one of the conclusions from the Daylighting project. It has been elaborated in the IEA SHC Task 61 with the special focus at users
- IEA SHC Task 61 / EBC Annex 77: "Literature review of user needs, toward user requirements" (2020) https://task61.iea-shc.org/Data/Sites/1/publications/IEA-SHC-Task61-Literature-Review-A1.pdf
- IEA SHC Task 61 / EBC Annex 77: "Integrated Solutions for Daylighting and Electric Lighting Subtask A: User perspective and requirements A.2 Use cases" (2021) https://task61.iea-shc.org/Data/Sites/1/publications/IEA-SHC-Task61--Technical-Report-A1.2-User-Perspective-and-Requirments-Use-Cases.pdf
- IEA SHC Task 61 / EBC Annex 77: Integrated Solutions for Daylighting and Electric Lighting Subtask A: User perspective and requirements. A.3 Personas (2021) https://task61.iea-shc.org/Data/Sites/1/publications/IEA-SHC-Task61--Technical-Report-A1.3-User-Perspective-and-Requirments-Personas.pdf

3. A general concern about the importance of daylight and view in buildings, vision and directions for research.
- Eleanor S. Lee, Barbara Matusiak, David Geisler-Moroder, Stephen Selkowitz, Lisa L Heschong "Advocating for view and daylight in buildings: Next steps" Energy and buildings, (2022) DOI: 10.1016/j.enbuild.2022.112079

[Norwegian University of Science and Technology, Faculty of Engineering, Department of Civil and Environmental Engineering] [1]

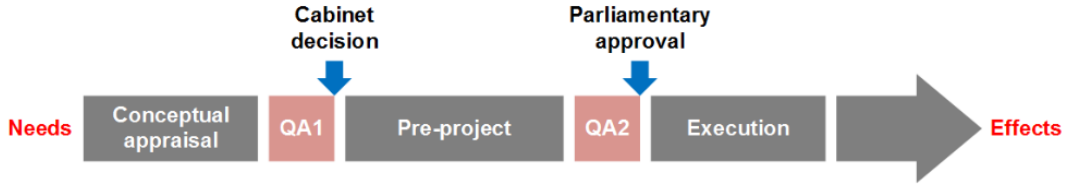
Institution: Norwegian University of Science and Technology (NTNU)
Administrative unit: Department of Civil and Environmental Engineering (IBM)
Title of case study: Concept Research Programme
Period when the underpinning research was undertaken: 2002-present (and ongoing)
Period when staff involved in the underpinning research were employed by the submitting institution: 2002-present
Period when the impact occurred: 2002-present

1. Summary of the impact

The Concept Research Programme develops ways of improving the efficiency and effectiveness of major public investment projects, with particular focus on the front-end phase. The programme follows the government's largest projects which are included in the so-called State Project Model (SPM). The programme has been funded by the Ministry of Finance since 2002. It is an example of a long-term engagement that has contributed to improved practices in ministries and agencies. Its' results are also used in education of civil engineers and prospective project managers. The results of the programme are regularly reported on in the international research literature.

2. Underpinning research (indicative maximum 500 words)

In the year 2000, the Norwegian government introduced a mandatory quality-at-entry regime for its largest investment projects. This was an answer to projects experiencing major cost and schedule overruns and benefit shortfalls. The current version of the scheme includes external quality assurance (QA) of the decision documents at two points in the project's planning process: before the government's choice of concept (QA1) and before the parliament's final approval (QA2). The regime was designed to improve analysis and decision-making, to ensure that the right projects were selected and that they were well-planned.



The Concept Research Programme follows the projects that are part of the scheme to accumulate information about the projects and their performance, develop improved tools and methods, and study the effects of QA and other measures taken during the front-end phase. The aim was to help the government (agencies and ministries, including the Ministry of Finance as scheme owner) learn and improve. Concept is often referred to as a trailing research program. The idea was to have a team of researchers trailing projects in real-time and providing feedback to the organizations responsible for the projects.

Among the research program's key activities are:

- Collect data from the projects. The projects range from railroad, public buildings, road, defense, to ICT and acquisition-projects. Collected data is systematically stored in a designated database (called Trailbase) that the research program manages.
- Conduct thematic studies on various topics, such as cost, financing, benefits, environmental impacts, contract strategies, project organizing, and policy decisions, using both qualitative and quantitative methods.
- In 2012 the Concept program introduced a framework for systematic ex-post evaluation of projects that are completed. Almost 40 projects have been evaluated so far, including

several high-profile projects such as the Opera in Oslo, the Hardanger Bridge, and the Skjold-class corvettes. Furthermore, these ex-post evaluations provide the basis for learning on meta-level.

- Extensive dissemination activities towards the Norwegian target group, including brief summaries and recommendations based on the research, holding seminars, webinars, workshops, and other types of dialogue with ministries, agencies and QA consultants.
- Collaboration with international researchers and dissemination of results in peer-reviewed journals and conferences. Also, Concept, together with the Ministry of Finance, hosts a biennial Symposium on Project Governance where resource persons from ministries, governmental agencies, academia, international organizations, and industry are invited.

Over time Concept has evidenced major improvement in public project practices, but also identified remaining and new challenges. Public projects in Norway are far more successful today than they were in the 1990s. Most projects are delivered within time and cost, much thanks to QA2. Whereas QA1 has led to some improvements in the earliest processes, there are still weaknesses related to, inter alia, scope and cost creep during and after the conceptual stage, benefits management, portfolio management, and the project owner role at the ministry level. Therefore, the research reports include numerous recommendations for improved practices. These recommendations also apply to the model itself and the Ministry of Finance as scheme owner.

A small and relatively stable research group (3-5 full-time researchers) has been based at the Department for Civil and Environmental Engineering from the start. The programme was established by Professor Knut Samset who was its' research director until he retired in 2020. The present research director has been with the group since 2011. The programme is also supported by a wider group of 15-20 researchers from different parts of NTNU and SINTEF. In addition, researchers from other universities are involved on a project-by-project basis.

Names of the key researchers since 2012 (not complete):

- Knut Samset, programme director 2002-2020
- Ole Jonny Klakegg, coordinator 2004-2010, at present member of the program's advisory board
- Gro Holst Volden, coordinator 2011-2020, director 2020-present
- Morten Welde, senior researcher 2013-present
- Ola Lædre, member of wider research group, 2002-present
- Atle Engebø, researcher 2021-present

3. References to the research

Below are only a few selected references. A broader overview of publications can be found here: https://www.ntnu.no/concept/publikasjoner

- Samset, K. and Volden, G.H. (2015). Front-end definition of projects: Ten paradoxes and some reflections regarding project management and project governance, *International Journal of Project Management 34*, 297–313
- Volden, G.H. and Welde, M. (2022). Public project success? Measuring the nuances of success through ex post evaluation, *International Journal of Project Management 40, 703-714*
- Samset, K. (2015). *Prosjekt i tidligfasen: Valg av konsept*, 2. utgave, Fagbokforlaget
- Engebø, A. og Lædre, O. (2023). Utfordringer i samspillsprosjekter. Concept-rapport nr. 74 https://www.ntnu.no/concept/concept-rapportserie
- Volden, G.H. and Samset, K. (2017). Quality assurance in megaproject management, the Norwegian way, book chapter in Flyvbjerg, B. (ed.) *The Oxford Handbook of Megaproject Management*, Oxford University Press, Oxford, 406-428

- Welde, M. and Klakegg, O.J. (2022). Avoiding Cost Overrun Through Stochastic Cost Estimation and External Quality Assurance, *Transactions on Engineering Management* https://hdl.handle.net/11250/3037155

4. Details of the impact

As of 2024, about 300 projects have been through the State Project Model. It is crucial that large projects funded by the taxpayers are well justified, implemented efficiently and that they deliver value for money. Concept's research has documented that over 70 per cent of all projects that have been through the model are delivered within budget. This stands in contrast to what is reported in the international literature and the situation in Norway in the 1990s.

Even marginal improvements in processes, tools and analyses may have a considerable economic impact on society, as well as the social and economic impact on users, neighbours and other stakeholders. Public project practices have improved considerably over time through the incentives inherent in the model, as well as trial and error, learning from previous projects, development and use of better tools and methods, exchange of experiences and dissemination of best practices. The Ministry of Finance has developed and improved the model itself over time, based on research and experience, and the current version of the model is mature in several aspects.

The Concept program has been instrumental in developing harmonized analyses and reviews in line with best practice. Concept has come to be seen as the hub for knowledge about large government investment projects in Norway. Over time, significant material has been produced, widely used and downloaded. The reports are in Norwegian to make them available for the target audience, and we always make summaries and focus on advice for practitioners. Printed editions of the reports are systematically sent to all related government departments, agencies, and quality-assurers. The Ministry of Finance and other actors refer to Concept for knowledge and advice, some agencies have started to evaluate their own projects using the Concept evaluation model, and we receive numerous inquiries and invitations yearly to give presentations, recommendations, participate in expert committees etc. The research program has a good reputation among stakeholders who share their data openly and willingly, whether it is documents, internal statistics, or allowing researchers to do interviews and observations. The program has an open approach towards idea generation by inviting and receiving ideas for new research projects from all its stakeholders. Concept also participates in dissemination and networking activities and generally maintains a good dialogue with the same stakeholders. The fact that the Ministry of Finance has continued to fund the program over all these years is a clear demonstration of its perceived relevance.

A study by the Association for Project Management (APM) and Project X in the UK investigated project research centres world-wide to study their profiles and role in relation to government and industry. This study highlighted the Concept Research Programme in Norway as one of the seemingly successful cases "encapsulating the 'triple helix' of research, education and engagement priorities" (Msulwa et al., 2020, p.9). They noted the long-term funding, the close collaboration with ministries and agencies, networking activities, and the balancing of short-term and long-term outputs have been beneficial.

Not only ministries and agencies that are obliged to follow the model, approach Concept for advice, but increasingly also organizations outside the scheme. We observe that similar schemes are being introduced for smaller projects and in other sectors, implying that learning has taken place far beyond the Ministry of Finance's scheme and those directly involved in it. Several regions and the biggest municipalities in Norway have introduced similar schemes for their biggest projects. The same is the case for investment projects run by health authorities and high voltage

electricity transmission and distribution projects, which are not included in the model since they are not directly part of the government but are state-owned enterprises.

There is also diffusion to other countries. Concept has done a lot to make the Norwegian model and experiences known internationally, through international conferences, journal papers, and meetings with government actors and international organizations like PMI (Project Management Institute), IMF, OECD, EU and others. The international Concept symposium has been held every 2 years since 2003 to learn from other countries and international top researchers. These initiatives are viewed as communities of practice.

Finally, the Concept Research Program has developed knowledge not only targeted at the actors currently involved in major projects, but also for future project managers and project owners through the education system. Books, reports and case examples from the program are extensively used in teaching, primarily at NTNU (project management), but also at other institutions, and many students each year write their master theses in relation to Concept.

5. Sources to corroborate the impact

- Series of short publications/pamphlets https://www.ntnu.no/concept/concept-temahefter
- Annual reports which provide information on activities including dissemination activities, website use etc. https://www.ntnu.no/concept/arsrapport
- Newsletter https://www.ntnu.no/concept/nyhetsbrev
- The Project X report Msulwa, R., Bloomfield, K., Young, P. and Lewis, M. (2020). Project & Programme Research Centres: Lessons for Scholarship, Policy and Practice. Report from APM and Project X https://www.apm.org.uk/v2/media/xeri2vwu/ppr-benchmarking-reportfinal.pdf
- Some examples of conferences with Concept as keynote speaker:
    - Styringskonferansen 2022 https://dfo.no/kurs-og-seminarer/konferanser-i-dfo/styringskonferansen#a7e566a9473bf1df4817891de50bdf46f
    - Dansk symposium 2023 https://danskprojektledelse.dk/symposium-2023/
- Use of Concept material in the Government's key document that describes economic perspectives for the country: Perspektivmeldingen 2021: https://www.regjeringen.no/no/dokumenter/meld.-st.-14-20202021/id2834218/
- Concept representatives in public expert committees:
    - Hagen-utvalget https://www.regjeringen.no/no/dokumenter/nou-2012-16/id700821/
    - Teknologiutvalget for transport https://www.regjeringen.no/no/dokumenter/teknologi-for-barekraftig-bevegelsesfrihet-og-mobilitet.-rapport-fra-ekspertutvalget---teknologi-og-fremtidens-transportinfrastruktur/id2662050/

[Norwegian University of Science and Technology, Faculty of Engineering, Department of Civil and Environmental Engineering] [2]

Institution: Norwegian University of Science and Technology (NTNU)
Administrative unit: Department of Civil and Environmental Engineering (IBM)
Title of case study: The Centre for Research-based Innovation SFI Klima 2050
Period when the underpinning research was undertaken: 2015 – 2023
Period when staff involved in the underpinning research were employed by the submitting institution: 2015 – 2023
Period when the impact occurred: 2016 - 2023

Summary of the impact

Throughout the lifetime of Klima 2050 major emphasis on innovation and the benefits of research to the Centre's user partners and society in general. Norwegian society is becoming increasingly aware of the need to adapt to climate change. The awareness has changed considerably during the 8 years of the Centre period. Large and small municipalities, companies, international actors, and the public have observed many of the activities taking place within the Centre and are getting in touch asking for advice and support in their work. We can clearly see that Klima 2050 activities will continue and become even more important into the foreseeable future.

Underpinning research

The Centre has produced a range of significant results within a broad set of topics relevant for risk reduction of building and infrastructure in respect of climate change. Predicting the impact a changing climate will have on buildings and infrastructure, is the first step in the process of finding suitable adaptation measures. Somewhat surprising research by the Centre reveals that climate-model-induced uncertainties are often under-communicated, due to either insufficient analysis or neglect.

On the building side, facades have been analysed. Harsh climatic conditions in the Nordic countries are being worsened by climate change, which increases the moisture load on building façades. New types of defects are being observed in air cavities in well-designed and well-built wooden façades and roofs, and more concern is necessary in planning, design, and construction. A building climate adaptation framework for Norway has been developed and the award "Statens pris for byggkvalitet" (The National Award for Building Quality) was given the Centre pilot project building ZEB Laboratory.

As climate change in the Nordic region brings an increase in extreme precipitation events, blue-green roofs have emerged as a solution for stormwater management. The addition of blue-green layers on a conventional compact roof represents several multi-disciplinary technical challenges and quality risks that must be managed. A framework intended to be used to reduce the building technical risks of blue-green roofs, by addressing the most important quality risk elements have been developed.

Green infrastructures have emerged as sustainable technologies for urban stormwater management. The Centre has advanced the national and international research in hydrological modelling, and through documentation of nature-based solutions (NBS) as mitigation measures through the many pilot projects. Just as important, a framework has been developed owing to the need for a systematic documentation of the applied NBS in accordance with the principles of infrastructure asset management and a newly adopted Norwegian Standard.

Landslide risk is increasing in wetter climate and mitigation is limited by data scarcity. The Centre has strongly contributed to the rapid development of investigation of how machine learning models and satellite images are most useful for landslide detection. Further information on how flexible barriers may be installed upstream in debris flow channels to reduce entrainment of bed

material in landslide situations has been provided. And in more general terms, an innovative webtool for landslide risk mitigation has been improved to include many nature-based solutions (NBS) for mitigating landslide risk.
Increased knowledge is necessary for the responsible stakeholders to enable them to take the right decisions, in both public and private organizations. A national web portal (Kunnskapsbanken) with access to all available data relevant to climate change adaptation has been launched in Norway. Through digitalization and close cooperation with insurance companies, the data in the web portal will improve. Klima 2050 has contributed to accelerating the development continuously by encouraging data sharing among insurance companies, the value of insurance data, and the potential to use these data to predict events. We have also addressed the municipalities' initial perceptions and experiences. Finally, an important contribution has been initiated in making a climate adaptation monitoring framework for municipalities in Norway.

1. References to the research

1. Time B (ed.): ***Final report.*** Klima 2050 Report 46. Trondheim 2023. ISBN 978-82-536-1806-7
2. Time B & Kvande T: ***Pilotprosjekter***. Klima 2050 Report 44. Trondheim 2023. ISBN 978-82-536-1796-1
3. Time B & Kvande T: ***Verktøy og veiledere for klimatilpasning***. Klima 2050 Report 43. Trondheim 2023. ISBN 978-82-536-1794-7
4. Time B & Kvande T: ***Spesialister i klimatilpasning***. Klima 2050 Report 42. Trondheim 2023. ISBN 978-82-536-1792-3
5. Time B & Kvande T: ***Partnerskapets innovasjoner***. Klima 2050 Report 41. Trondheim 2023. ISBN 978-82-536-1790-9

4. Details of the impact

The building and construction sector consists of more than 50,000 companies and employs about 250,000 people, all of whom must contribute to the best of their ability towards reducing societal risk and adapting buildings and infrastructure to the threats posed by climate change. Much of our research is made available to the sector and those who work there.
We have taken part in several projects and co-creational initiatives with players in the private and public sectors and other research centres, focusing on issues of interest also to many stakeholders outside the Centre’s partnership group. We have developed guidelines that are of benefit to the municipalities and have participated in the work to revise BREEAM-NOR, which is the most frequently applied building certification system in Norway. We link our research to other Norwegian initiatives and projects such as the Natural Hazards Forum, the Norwegian water sector organisation Norsk Vann, and SINTEF Building Research Design Guides. These are important fora for the dissemination of our research results.
In total, the Centre established 16 pilot projects. Pilots have been the Centre's main arena for product and process development and the testing of research results. They have been an effective means of disseminating know-how generated at the Centre. Such projects have also been excellent opportunities to showcase the Consortium. Klima 2050 has resulted in close to 1500 scientific articles, reports, popular science articles, chronicles, and presentations, where some articles have received international awards. Klima 2050 researchers have given several keynote/invited lectures. 18 PhD and 135 MSc candidates will complete their theses in connection to Klima 2050 and 7 pos.docs have been engaged in the Centre, securing national and international dissemination of knowledge about risk reduction and climate adaptation into planning and construction processes and in society. The Klima 2050 researchers and partners have engaged several national and international (EU) activities, and the Centre has exchanged incoming and outgoing researchers.
All the way through the Centre period the research plan has been organized in four main areas; WP1 Climate exposure and moisture-resilient buildings, WP2 Stormwater management in small

catchments, WP3 Landslides triggered by hydro-meteorological processes, and WP4 Decision-making processes and impact.
Goals, knowledge gaps to be filled and research tasks were stated in the Klima 2050 Project description. Biannual working plans were developed throughout the Centre period. The Research Working Plans were supplement to the Klima 2050 Project description. Every two years a process was initiated during summer with partner meetings, the first years common meetings, the last years separate meetings with all the partners to get input to research tasks. The Center Management Group has tried their best to balance and consider the input from the partners. The plans always reflected interests from the partners and to a certain extent direct input and proposals was incorporated in the plans.
How to focus innovation shifted after two years time. The original idea with an "Innovation Forum" did not work out as intended, it turned out to be too vague and not concrete enough. It was also difficult to engage user partners. Hence, the focus was changed, and more concrete activities was suggested. "Innovation through pilot projects" was established instead. Our experience demonstrates that pilots promote productive interaction between the partners involved and they showed to be a successful arena for innovation, product development and the testing of research results. The pilots have also regarded as an effective means of disseminating know-how generated at the Centre.
We have had a strong focus on real cooperation between partners and have initiated different activities to promote that. *Partner meetings* were held with the aim of promoting input and dialogue in connection with activities taking place at the Centre. Such meetings were held primarily in connection with the preparation of work plans and/or at the request of the consortium partners. Partner meetings was held with individual partners, or among groups of partners.
Thematic meetings (59 in total) were organised activities that encompassed all or parts of the consortium with the aim of contributing towards knowledge dissemination, experience and research exchange, and innovation. Such gatherings have been very much appreciated by the partners and important with a view to knowledge exchange and are arenas in which researchers can obtain direct input to their work, and we found areas where the partners could work more closely. Among other things, the thematic meetings included; work meetings, seminars, excursions, pilot projects, Ph.D. tutorials and Klima 2050-dagen.

5. Sources to corroborate the impact

- Achievements from Klima 2050
- Key performance indicators for Science and Innovations
- Publikasjonsliste Klima 2050
- Eksempelsamling for overvannstiltak
- ZEB-laboratoriet i Trondheim tildelt Statens pris for byggkvalitet
- Når drømmer blir realisert i Klima 2050
- Mer regn og bedre regelverk gir andre typer byggskader
- Blågrønne tak - viktig bidragsyter til god overvannshåndtering
- Nytt rammeverk for prosjektering av blågrønne tak
- Isola har fått SINTEF Teknisk Godkjenning (TG) for bruk av smart dampsperre i kompakte tretak

[Norwegian University of Science and Technology, Faculty of Engineering, Department of Civil and Environmental Engineering] [3]

Institution: Norwegian University of Science and Technology (NTNU)
Administrative unit: Department of Civil and Environmental Engineering (IBM)
Title of case study: SAMCoT
Period when the underpinning research was undertaken: 2011-2019
Period when staff involved in the underpinning research were employed by the submitting institution: 2011 - 2019
Period when the impact occurred: 2015 - continued

1. Summary of the impact

The SFI SAMCoT carried out fundamental and applied research about ice and ice actions on fixed and floating structures (including ships) and the design and operation of coastal infrastructure on permafrost. New software was developed, and international standards were improved. The three main innovation topics were modelling of a) ice action on floaters, b) ice-induced vibrations and c) thermo-mechanical behaviour of permafrost. New and unique data was gathered and made available for partners and society at large. SAMCoT was the basis for new European and national research projects (e.g. FATICE 2018-2021 and RareIce 2021-2025).

2. Underpinning research

The software SAMS was developed by several researchers on NTNU and TU-Delft. Post-Doc and Associate Professor Raed Lubbad, Professor Sveinung Løset, PhD and post-doc Wenjun Lu, PhD and Post-doc Andrei Tsarau at NTNU as well as PhD and Post-Doc at TU-Delft Marnix van-den Berg. It builds on many years of development at NTNU of using Discrete Element Method (DEM) to simulate sea ice motion and their interaction with floating structure and ships, extensive field work on both ice properties and full-scale trials in the Arctic with icebreakers. The full-scale trials were used to calibrate and validate the software. One important innovative element is the implementation of an effective numerical time-stepping allowing the model to run fast enough for the relevant applications.

The numerical model to simulate ice-induced vibrations for fixed structures called VANILLA was developed by PhD student Hayo Hendrikse and Professor Andrei Metrikine at TU-Delft in close collaboration with PhD student and Post-doc Torodd Nord from NTNU and Professor Emeritus Mauri Määttänen from Aalto. The development was based on analysis of existing full-scale data, extensive model basin testing as well as field work on ice mechanical properties. The model includes a unique compromise between fundamental ice mechanics and applied structural dynamics, and it is the first model that can simulate the observed velocity dependent ice-induced vibrations. The model could not have been developed without the combined world leading long-term research on structural dynamics at TU-Delft and Aalto with the world leading research on ice mechanics at NTNU and UNIS.

The development of a unique thermo-hydro-mechanical constitutive model for Finite Element modelling (FEM) was completed and implemented by NTNU Post-Doc and Researcher Seyed Ali Ghoreishian Amiri in collaboration with Professor Gustav Grimstad. It combined the three different critical phenomena of mechanical and thermal in porous media and fluid flow through a porous media.

3. References to the research

- Tsarau, A. and Løset, S. Modelling the hydrodynamic effects associated with station-keeping in broken ice. Journal of Cold Regions Science and Technology.
- Berg, vd M., Lubbad, R. and Løset, S. - An implicit time-stepping scheme and an improved contact model for ice-structure interaction simulations. Journal of Cold Regions Science and Technology.
- Lubbad, R., Løset, S., Lu, W., Tsarau, A. and vd Berg, M. - An overview of the Oden Arctic Technology Research Cruise 2015 (OATRC2015) and numerical simulations performed with SAMS driven by data collected during the cruise 2015 (OATRC). Journal of Cold Regions Science and Technology
- Hendrikse, H. and Nord, T.S., 2019. Dynamic response of an offshore structure interacting with an ice floe failing in crushing. Marine Structures, 65, pp. 271-290.
- Hendrikse.,H., Ziemer, G. and Owen, C.C. - Experimental validation of a model for prediction of dynamic ice-structure interaction. Journal of Cold Regions Science and Technology
- Rostami, H., Amiri, A.G. and Grimstad, G. - Back analysis of Caen's test by the recently developed frozen/unfrozen soil model. Plaxis Bulletin.

4. Details of the impact

The success in the SFI lies in a combination of good funding, a good background with many years of applied and fundamental research within the topics and the applied nature of the SFIs.

The success of the three impact cases was that they combined fundamental understanding of physical processes, substantial full-scale and model-scale experimental data, very good ability for numerical implementation with a drive to create an application.

The arctic region is characterized by complex processes, little data (difficult and expensive to measure relevant properties), vulnerable nature and scares population. It was the need for energy that drive the industrial contributors and the impact cases have created applied numerical tools to allow for simulations of vital processes allowing for the design and operation of infrastructure.

SAMS has been applied in the following projects:

Project	Year	Client	Activities
FORNY 2020	2017-2018	RCN	Development and validation of SAMS
NORD ST19	2018	Petroleum Safety Authority	Assessment of structural Damage due to Glacial Ice Impact
Wisting field	2019	OMV	Second opinion ice studies
Northguider	2019	Coastal administration	Simulation of ice loads
NORD ST20_2019/313	2019	Petroleum Safety Authority	Loads, design, operations of floaters in the North

The software VANILLA is one of two software that have been certified by DNV and is used by the European Wind industry (for example Siemens Gamesa, Rambøll). It is also used in numerous projects by TU-Delft in consulting projects for wind parks in the Baltic (for example Kriegers flak in Danish waters).

The hydro-thermo-mechanical permafrost model drew the attention of a commercial software company "Plaxis" (https://www.Plaxis.com/ support/models/frozen-and-unfrozen-soil-model/). It is

now implemented in their software and receives worldwide exposure in this specific field to the benefit of society as a whole.

5. Sources to corroborate the impact

- ISO19906 Arctic Offshore Structures, Petroleum and natural gas industries, https://www.iso.org/standard/65477.html
- IEC 61400-3-1:2019, Wind energy generation systems - Part 3-1: Design requirements for fixed offshore wind turbines (https://webstore.iec.ch/publication/29360)
- **PLAXIS (https://www.seequent.com/products-solutions/plaxis/) -** (https://www.Plaxis.com/ support/models/frozen-and-unfrozen-soil-model/).

[Norwegian University of Science and Technology, Faculty of Engineering, Department of Civil and Environmental Engineering] [4]

Institution: Norwegian University of Science and Technology (NTNU)
Administrative unit: Department of Civil and Environmental Engineering (IBM)
Title of case study: Norwegian Winter Maintenance Research Centre
Period when the underpinning research was undertaken: 2012-2020
Period when staff involved in the underpinning research were employed by the submitting institution: 2012-2020
Period when the impact occurred: 2014-2020

1. Summary of the impact

The knowledge generation performed at Norwegian Winter Maintenance Research Centre (forskningssenter vinterdrift), has directly led to, or significantly contributed to, the following impacts: 1) new National guidelines for salt usage in Norway, 2) new training program for winter maintenance personnel (annually about 2000 salt truck drivers take the exam), 3) New standard for winter maintenance of bicycle lanes. 4) A decision support model, implemented at 42 airports, and 5) adaptations to ICAO's global reporting format for runway surface conditions.

2. Underpinning Research

Prior to 2012, winter maintenance in Norway relied predominantly on practical experience, resulting in significant knowledge gaps regarding the actual workings of salt or other anti-/de-icing chemicals. In 2012, NTNU initiated the "Forskningssenter Vinterdrift,", funded by Statens Vegvesen. Beginning with two PhDs and one Postdoc, our research focused on the physics of anti-icing (preventing slippery roads/runways), anti-compaction (using salt during snowfall to prevent compaction), and de-icing (melting ice below 0°C).

<u>Impact 1 and 2</u>

The first key research insight revealed that, for wet pavements, significantly less salt could be used than the freezing point depression suggested. This is due to the fact that salt, besides depressing the freezing point, also weakens the ice if water freezes. This weakened ice does not survive the mechanical loading from the traffic, gets disintegrated and the underlying road surface remains available to create friction. The primary study [1], conducted in 2012-2013 provided a new way of calculating minimum salt dosage. The work was expanded with a PhD on hoar frost formation on salted roads from 2015-2019 and several MSc studies. The main contributors being Johan Wåhlin (Postdoc), Janne Siren Fjærestad (PhD), and Alex Klein-Paste (Professor).

The second key insight focused on how dissolved salt (or other chemicals) weakens the bond between snow crystals. The initial paper [2] outlined the mechanism by which diluted salt solutions between snow grains hinder sintering and documented the impact of solution content. Subsequent studies concluded that snow needs to contain at least a 5% solution (at equilibrium concentration) to prevent compaction. This research spanned from 2012-2019, with the main contributors being Johan Wåhlin (Postdoc), Henri Giudici (PhD), and Alex Klein-Paste (Professor).

The last key insight pertained to de-icing, encompassing studies on both the melting capacity and rate of deicers. It was discovered that the prevailing standard poorly measured melting capacity, leading to the development of a new testing method. The research also identified mass diffusion as a key factor influencing melting rates. This work took place from 2015-2021, with primary

contributors being Johan Wåhlin (Postdoc), Kine Nilssen (PhD), Sergey Kulyahtin (PostDoc), and Alex Klein-Paste (Professor).

Impact 3

Motivated by the necessity to improve winter walking and cycling conditions, two PhD studies were conducted in close collaboration with Statens Vegvesen. These studies explored the rolling resistance experienced by snow/ice and how the willingness to cycle depended on this resistance. Additionally, investigations into how standards affected winter walking, slip and fall accidents, and "close calls" were conducted. Findings from these studies, combined with economic and practical considerations, played a crucial role in shaping new standards for sidewalks and bicycle lanes. Main contributors included Magne Fossum (PhD), Eirin Ryeng (Professor), Mathis Dahl Fenre (PhD), and Alex Klein-Paste (Professor).

Impact 4 and 5

The winter maintenance of runways, particularly the braking friction of in-service commercial aircraft, has been a long-term study field for our group, in collaboration with Avinor (Hans Jørgen Bugge), the University of Oslo (Professor Arne Bang Huseby), and Boeing (Paul Giesman). Avinor received landing data from SAS and Norwegian, UiO handled all big data processing, while NTNU conducted the final analysis. Our group examined the braking friction experienced by aircraft operating on snow/ice-contaminated runways. In 2012, a decision support model was developed and has since been adapted and updated based on new research results and changes in ICAO's global reporting format. The available data was instrumental in ensuring the acceptance of "specially prepared winter runways" in the global reporting format. The main contributor from NTNU was Alex Klein-Paste (Professor).

3. References to the research

[1] Klein-Paste, A. and J. Wåhlin, *Wet pavement anti-icing - A physical mechanism.* Cold Regions Science and Technology, 2013. **96**(0): p. 1-7.
[2] Wåhlin, J., S. Leisinger, and A. Klein-Paste, *The effect of sodium chloride solution on the hardness of compacted snow*. Cold Regions Science and Technology, 2014. 102(0): p. 1-7.
[3]Nilssen, K.,A. Klein-Paste, J. Wåhlin, M.A. Delapaz, *Use of Calorimetry to Measure Ice-Melting Capacity.* Transportation Research Record, 2017. **2613**(1): p. 1-7.
[4] Fossum, M. and E. O. Ryeng (2021). *"The walking speed of pedestrians on various pavement surface conditions during winter."* Transportation Research Part D: Transport and Environment **97**:102934
u.
[5] Klein-Paste, A., et al., *Braking performance of commercial airplanes during operation on winter contaminated runways.* Cold Regions Science and Technology, 2012. **79**–**80**: p. 29-37.
[6] Klein-Paste, A., H.-J. Bugge, and A.B. Huseby, *A decision support model to assess the braking performance on snow and ice contaminated runways.* Cold Regions Science and Technology, 2015. **117**: p. 43-51

4. Details of the impact

Impact 1) National guideline for salt usage (2014)

D2-ID9300a Bruk av salt [7] is the official Norwegian guideline for the use of salt. The guidelines are implemented in all contracts for all state roads (~11 000km). But many counties and municipalities either directly use the guidelines or base their own guiding materials on this document. The differentiation between anti-icing and anti-compaction and the recommended dosages were made as a direct result from our developed insights into salt-snow interactions. Statens Vegvesen (Kai-Rune Lysbakken) and NTNU had a very close collaboration with many informal scientific discussions that led to the guidelines. A sector network (Bransjenettverk vinterdrift) was used for discussions and feedback prior to implementation.

Impact 2) new training program for winter maintenance personnel (2022)
Statens vegvesen has developed and formalized the training of truck drivers working on their maintenance contracts. Øystein Larsen (SVV) was a key person in this process. The textbook [8] contains several chapters that are based on the knowledge that NTNU generated on how salt works and provided input for the training program. In addition, NTNU has organized several courses for about 1000 practitioners. Today the main contractors teach the course for their own employees and their sub-contractors. Annually about 2000 truck drivers take the exam annually.

Impact 3) New standard for winter maintenance of bicycle lanes (2021)
Our research on rolling resistance for bicycles and user behavior on sidewalks provided critical input that shaped the development of a new standard for sidewalks and cycleways in Norway [9]. Bård Nonstad (SVV) and Katja Skille (SVV) led the implementation process and NTNU have been in continuous dialog with them during this process.

Impact 4) IRIS, A decision support system, now implemented at 42 airports (2015,2017, 2022)
Avinor's Integrated Runway Information System (IRIS) contains a model [4] that is developed by NTNU. Significant modifications were made in 2015, 2017 and 2022, integrating our research results on braking friction of commercial aircraft [5,6] and make it compliant with new ICAO reporting format [7]. The runway condition model is now implemented at 42 airports, helping runway inspectors to correctly assess the surface conditions of runways.

Impact 5) Adaptations to ICAO's New Global Reporting Format for Runway Surface Conditions
After a long harmonization process in the aviation sector (2014-2020) the new Global Reporting Format (GRF) for Runway Surface Conditions has been fully implemented. The international Civil Aviation Organization (ICAO), in cooperation with the major stakeholders (authorities, aerodrome operators, aircraft manufacturers and airliners) implemented this global change in legislation and technical guidance material. The Norwegian dataset of on braking performance and the analysis done by NTNU were crucial to get acceptance for "specially prepared winter runways". Without it, several airports (e.g. Kirkenes, Svalbard, Alta, Bardufoss) would suffer heavily and not be operative for several weeks/months during wintertime.

5. Sources to corroborate the impact

[7] SVV, *Instruks D2-ID9300a Bruk av salt* https://www.vegvesen.no/s/anbud/dkmal2023/
[8] Larsen m.fl, 2022 *Opplæring i vinterdrift for operatører*, report 832, Vegdirektoratet, https://vegvesen.brage.unit.no/vegvesen-xmlui/handle/11250/3011015
[9] SVV, Nye krav til brøyting av gang- og sykkelarealer https://www.vegvesen.no/om-oss/presse/aktuelt/2022/01/nye-krav-til-broyting-av-gang--og-sykkelarealer/
[4] Klein-Paste, A., H.-J. Bugge, and A.B. Huseby, *A decision support model to assess the braking performance on snow and ice contaminated runways.* Cold Regions Science and Technology, 2015. **117**: p. 43-51
[5] Klein-Paste, A., et al., *Braking performance of commercial airplanes during operation on winter contaminated runways.* Cold Regions Science and Technology, 2012. **79–80**: p. 29-37.
[6] Klein-Paste, A., *Airplane braking friction on dry snow, wet snow or slush contaminated runways.* Cold Regions Science and Technology, 2018. **150**: p. 70-74.
[7] ICAO (2021), *The new Global Reporting Format for Runway Surface Conditions*, International Civil Aviation Organisation, https://www.icao.int/safety/Pages/GRF.aspx

[NTNU / IE-Faculty / IEL Institute / Group: EME] [case No 1]

Institution: NTNU- Norwegian University of Science and Technology
Administrative unit: IE-Faculty of Information Technology and Electrical Engineering / IEL - Department of Electric Energy **Research group: EME - Electrical Machines and Electromagnetics**
Title of case study: Kongsberg Maritime AS/Rolls Royce Electrical AS.
Period when the underpinning research was undertaken: 2012 – 2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2012 – 2022
Period when the impact occurred: 2012 - 2022

1. Summary of the impact (indicative maximum 100 words)
This section should briefly state what specific impact is being described in the case study.

SmartMotor AS established in 1996 in Trondheim, offered customized electrical machines with associated control systems and power electronics. The basis of the concept is patented Permanent Magnetic (PM) technology in combination with integrated gearless systems. Most machine designs are adapted to special applications - and often operated in very demanding environments. The PM motor designed by SmartMotor have typically been integrated with the application designs, making the PM –motors an enabling technology. SmartMotor originates from NTNU in Trondheim and has served customers such as Rolls Royce Marine, Aker Solutions, Statoil, Kongsberg and Siemens.

SmartMotor was acquired by Rolls Royce Marine AS in 2013.

Merged with Rolls Royce Marine in 2016.

When Kongsberg AS acquired Rolls Royce Marine AS, the department in Trondheim was transferred to Rolls Royce Electrical AS in2018. [Org Id: 921045379 MVA]

2. Underpinning research (indicative maximum 500 words)
This section should outline the key research insights or findings that underpinned the impact, and provide details of what research was undertaken, when, and by whom. This research may be a body of work produced over a number of years or may be the output(s) of a particular project. References to specific research outputs that embody the research described in this section, and evidence of its quality, should be provided in the next section. Details of the following should be provided in this section:

- The nature of the research insights or findings which relate to the impact claimed in the case study.
- An outline of what the underpinning research produced by the submitted unit was (this may relate to one or more research outputs, projects or programmes).
- Dates of when it was carried out.
- Names of the key researchers and what positions they held at the administrative unit at the time of the research (where researchers joined or left the administrative unit during this time, these dates must also be stated).
- Any relevant key contextual information about this area of research.

Period 2005 – 2010:
The research started with the focus on low-speed application with a demand for fault tolerant Permanent Magnet motors. The application area was wide, ranging from wind generators, marine propulsion to wheel motors used in wheelchairs.

Period 2010– 2013:
The outcome from this basic research was a series of practical and manufacturing oriented designs with concentrated single layer windings. In the beginning both radial and axial flux motors where investigated. The large axial flux machines were designed for wind generators while large radial flux machines where specially designed for marine applications.

Prototype for large radial flux machines for marine application

Period 2013 – 2022:
The radial flux concentrated coil winding machines are now used in marine applications such as Marine Winches [PM Anchor winches], In board marine propulsion motors [TT PM-Thrusters], outboard rim drive propulsion motors [Azipull-PM thruster] and special purpose (very deep operation) motors for submarines [Hugin PM motor].
See reference to Products in item; **4. Details of the impact**

A series of master students participated in this research.
Detailed description of PhD thesis and research, listed in chapter **3. References to the research**.

3. References to the research (indicative maximum of six references)
This section should provide references to key outputs from the research described in the previous section, and evidence about the quality of the research. All forms of output cited as underpinning research will be considered equitably, with no distinction being made between the types of output referenced.

All outputs cited in this section must be capable of being made available to panels. If they are not available in the public domain, the administrative unit must be able to provide them if requested by RCN or the evaluation secretariate.

1.
- Author(s): Krøvel, Øystein
- Title: Design of Large Permanent Magnetized Synchronous Electric Machines:
  Low Speed, High Torque Machines
  - Generator for Direct Driven Wind Turbine
  - Motor for Rim Driven Thruster
- Year of publication: (Doktoravhandlinger ved NTNU, 1503-8181; 2011:25, Doctoral thesis, 2011)
- Type of output and other relevant details required to identify the output (for example, DOI, journal title and issue):
Design of two prototype permanent magnetized electric machines for two different applications where large permanent magnet machines might be used.
- Details to enable the panel to gain access to the output, if required (for example, a DOI or URL)
https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/256994

2.
- Author(s): Astrid Røkke
- Title: Permanent Magnet Generators For Marine Current Tidal Turbines
- Year of publication: PhD Doctoral thesis,NTNU, 2017
- Type of output and other relevant details required to identify the output (for example, DOI, journal title and issue): - Details to enable the panel to gain access to the output, if required (for example, a DOI or URL):
design of a permanent magnet generator for a marine current turbine, more specifically a tidal turbine. The content is in addition also applicable for marine applications.
https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/2443994

3.
- Author(s): Zhaoqiang, Zhang
- Title: Ironless Permanent Magnet Generators For Direct-Driven Offshore Wind Turbines
- Year of publication: Doctoral thesis at NTNU;2015:138, Doctoral thesis, 2015
- Type of output and other relevant details required to identify the output (for example, DOI, journal title and issue):
Investigate the iPMG (ironless Permanent Magnet Generator) technologies with the help of advanced modelling approaches.
- Details to enable the panel to gain access to the output, if required (for example, a DOI or URL):
NTNU Open: IRONLESS PERMANENT MAGNET GENERATORS FOR DIRECT-DRIVEN OFFSHORE WIND TURBINES

4.
- Author(s): Severson, Eric; Røkke, Astrid; Nilssen, Robert; Undeland, Tore Marvin; Mohan, Ned
- Title: Design and measurement of a passive thrust magnetic bearing for a bearingless motor
- Year of publication: (IEEE Industrial Electronics Society. Annual Conference. Proceedings;IECON 2013, Journal article; Peer reviewed, 2013)
- Type of output and other relevant details required to identify the output (for example, DOI, journal title and issue):
The design and construction of a permanent magnet thrust bearing for a bearingless motor is presented and a measurement technique is proposed to characterize the bearing.
- Details to enable the panel to gain access to the output, if required (for example, a DOI or URL):
NTNU Open: Design and measurement of a passive thrust magnetic bearing for a bearingless motor

5.
- Author(s): Lagerström, Anders
- Title: Design of Large PM-Generators for Wind Power Applications
- Year of publication: Master thesis, 2011
- Type of output and other relevant details required to identify the output (for example, DOI, journal title and issue):
This report describes generator design for wind power applications. It explains a modern design procedure which uses both analytical and numerical analysis. The numerical analysis uses finite element analysis and in this report it is performed in Comsol. The report is done in cooperation with the industrial company, SmartMotor AS.
The content is in addition to Wind power applications, also applicable for marine applications
- Details to enable the panel to gain access to the output, if required (for example, a DOI or URL)
NTNU Open: Design of Large PM-Generators for Wind Power Applications

4. Details of the impact (indicative maximum 750 words)

This section should provide a narrative, with supporting evidence, to explain:

- How the research underpinned (made a distinct and material contribution to) the impact
- The nature and extent of the impact

The following should be provided:

- A clear explanation of the process or means through which the research led to, underpinned or made a contribution to the impact (for example, how it was disseminated, how it came to influence users or beneficiaries, or how it came to be exploited, taken up or applied).
- Where the submitted administrative unit's research was part of a wider body of research that contributed to the impact (for example, where there has been research collaboration with other institutions), the case study should specify the particular contribution of the submitted administrative unit's research and acknowledge other key research contributions.
- Details of the beneficiaries – who or what community, constituency or organisation has benefitted, been affected or impacted on.
- Details of the nature of the impact – how they have benefitted, been affected or impacted on.
- Evidence or indicators of the extent of the impact described, as appropriate to the case being made.
- Dates of when these impacts occurred.

SmartMotor - Rolls Royce Marine - Rolls Royce Electrical:

Rolls Royce Electrical:

Electrical team readies for its biggest power challenge | Rolls-Royce

Helping autonomous underwater vehicles map the ocean floor | Rolls-Royce

Rolls-Royce Electrical in Norway makes the top 3! | Rolls-Royce

HUGIN

Autonomous Underwater Vehicle - AUV - HUGIN - Kongsberg Maritime

With PM-machine from RRE:

Helping autonomous underwater vehicles map the ocean floor | Rolls-Royce

Number of employees in Rolls Royce Electrical AS, Trondheim:

- Employees 2012: Ca 30
- Employees 2022: Ca 56

Products in Kongsberg Maritime arising from Permanent Magnetic (PM) technology:

1. **Product Commercialisation:** 2014

Kongsberg Marine (former Rolls Royce Marine) .
Production of electrical PM-machines for maritime applications.
Kongsberg Marine has established a new production line of Rim drive PM-Thrusters in Ulsteinvik, based on the electromagnetic design from SmartMotor/ Rolls Royce Marine.
Both Tunnel Thrusters and Azimuth Thruster.

[Permanent Magnet tunnel thruster RD-TT 1600 - Kongsberg Maritime]

[Permanent Magnet tunnel thruster RD-TT 2000 - Kongsberg Maritime]

[Permanent Magnet azimuth thruster RD-AZ 1900 - Kongsberg Maritime]

[Permanent Magnet azimuth thruster RD-AZ 2600 - Kongsberg Maritime]

Number of employees in Kongsberg Maritime working with PM-Thrusters: Approx: 30-35
Mainly in Ulsteinvik and Ålesund

2. Product Commercialisation: 2015?
Kongsberg Maritime (former Rolls Royce Marine) .
"Anchor handling / towing winches for offshore vessels is one of our specialties. … They are offered with three drive systems, LP hydraulic, AC electric or PM (permanent magnet motor) electric."
With SmartMotor/ Rolls Royce Marine Permanent Magnet motor -design.
[Anchor handling and towing winches for anchor handling vessel - Kongsberg Maritime]

[Brattvåg: Serieproduserer elektromotor i hydraulikkmekka - Tu.no]

Number of employees in Kongsberg Maritime working with PM-Winch: Approx: 5-10
Mainly in Brattvåg and Ålesund

3. Product Commercialisation: 2014
Kongsberg Maritime (former Rolls Royce Marine) .

Azipull-PM thruster (AZP-PM)

With Permanent Magnet motor -design from Rolls Royce Marine Trondheim, former SmartMotor.

[Azipull thruster - Kongsberg Maritime]

Number of employees in Kongsberg Maritime working with Azipull-PM thruster: Approx: 5-10
Mainly in Ulsteinvik and Ålesund
Production in Finland

5. Sources to corroborate the impact (indicative maximum of ten references)

Name, Company	Role	Email
Gunnar Johnsen, Kongsberg Maritime	Manager, Power Electrical System Propulsion and Engine	gunnar.johnsen@km.kongsberg.com
Sigurd Øvrebø Rolls Royce Electrical	Managing Director	Sigurd.Ovrebo@Rolls-Royce.com

[NTNU / IE-Faculty / IEL Institute / Group: EME] [case No 2]

Institution: NTNU- Norwegian University of Science and Technology
Administrative unit: IE-Faculty of Information Technology and Electrical Engineering / **IEL - Department of Electric Energy** **Research group: EME - Electrical Machines and Electromagnetics**
Title of case study: Alva Industries AS
Period when the underpinning research was undertaken: 2012-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2015 - 2022
Period when the impact occurred: 2017 - 2022

1. Summary of the impact (indicative maximum 100 words)

Alva Industries AS is a start-up company based in Trondheim that uses an in-house developed production technology to produce light, highly efficient electric motors.
ALVA Industries was funded in 2017, with support from NTNU TTO.
NTNU Technology Transfer AS (ntnutto.no)

The founder Jørgen Selnes was a student at NTNU Entrepenørskolen
NTNU School of Entrepreneurship (entreprenorskolen.no)

The company was established to meet the world's growing energy needs with sustainable technologies and aims to develop the world's best electric drive systems to enable the electrification of several sectors and industries.

2. Underpinning research (indicative maximum 500 words)

This section should outline the key research insights or findings that underpinned the impact, and provide details of what research was undertaken, when, and by whom. This research may be a body of work produced over a number of years or may be the output(s) of a particular project. References to specific research outputs that embody the research described in this section, and evidence of its quality, should be provided in the next section. Details of the following should be provided in this section:

- The nature of the research insights or findings which relate to the impact claimed in the case study.
- An outline of what the underpinning research produced by the submitted unit was (this may relate to one or more research outputs, projects or programmes).
- Dates of when it was carried out.
- Names of the key researchers and what positions they held at the administrative unit at the time of the research (where researchers joined or left the administrative unit during this time, these dates must also be stated).
- Any relevant key contextual information about this area of research.

Founder of Alva was partly inspired with the research on ironless machines at EME and contacted Professor Robert Nilsen to evaluate on the possibilities to use ironless machines in different applications suitable for the ALVA business case.

The design of motors from ALVA is founded on two technologies:

1 . Ironless slotless permanent motor technology
2. FiberPrinting of the windings in the stator

Where the first technology element, Ironless, slotless, PM technology is a core technology from NTNU / IEE/EME.

Research on Ironless slotless permanent motor technology has been a focused activity at Eme since 2010, and a prototype for ironless axial-flux permanent motor was built and used on NTNU/Eme -Lab.

ALVA Industries has cooperated with NTNU / IEE/EME on several BSc and MSc projects:

BSc 2020: Thomas Rendall Berg, Morten Karlsen, Bård Jakob Malmo, Gustav Georgescu Solbrekken, "Design og dimensjonering av elektrisk fremdriftssystem for helikoptre og droner"
MSc 2022: Andreas Killingberg "Hybrid Slotless Permanent Magnet Machines as a Disruptive Solution for Electric Vehicles" Fredrik Opdal "Design of a Hybrid Winding PM Machine for Electric Aviation"

One of the employees at ALVA- Matteo Leandro defended his PhD thesis at EME:

PhD thesis at EME 2023: Matteo Leandro “Framework for Analytical-based Digital Twin Development of Electric Drive Using Slotless PM Machines”

Another employee: Alexey Matveev - Research & IP Director at ALVA Industries,
has a position as Professor II at EME NTNU, [alexey.matveev@ntnu.no]

Other employees are coming from EME NTNU, as BSc-, or MSc students: Kasper Kvinnesland

3. References to the research (indicative maximum of six references)

This section should provide references to key outputs from the research described in the previous section, and evidence about the quality of the research. All forms of output cited as underpinning research will be considered equitably, with no distinction being made between the types of output referenced. Include the following details for each cited output:

- Author(s)
- Title
- Year of publication
- Type of output and other relevant details required to identify the output (for example, DOI, journal title and issue)
- Details to enable the panel to gain access to the output, if required (for example, a DOI or URL)

All outputs cited in this section must be capable of being made available to panels. If they are not available in the public domain, the administrative unit must be able to provide them if requested by RCN or the evaluation secretariate.

1
- Author(s): Thomas Rendall Berg, Morten Karlsen, Bård Jakob Malmo, Gustav Georgescu Solbrekken,
- Title: BSc - "Design og dimensjonering av elektrisk fremdriftssystem for helikoptre og droner"
- Year of publication: 2020
- Type of output and other relevant details required to identify the output (for example, DOI, journal title and issue): Relevant for the design of the drone and control converter at ALVA Industries
- Details to enable the panel to gain access to the output, if required (for example, a DOI or URL):
NTNU Open: Design og dimensjonering av elektrisk fremdriftssystem for helikoptre og droner

2
- Author(s): Fredrik Opdal
- Title: MSc - "Design of a Hybrid Winding PM Machine for Electric Aviation"
- Year of publication: 2022
- Type of output and other relevant details required to identify the output (for example, DOI, journal title and issue): Relevant for the design of the winding used in the drone at ALVA Industries.
- Details to enable the panel to gain access to the output, if required (for example, a DOI or URL):
NTNU Open: Design of a Hybrid Winding PM Machine for Electric Aviation

3
- Author(s): Andreas Killingberg
- Title: MSc - "Hybrid Slotless Permanent Magnet Machines as a Disruptive Solution for Electric Vehicles"
- Year of publication: 2022
- Type of output and other relevant details required to identify the output (for example, DOI, journal title and issue): Relevant for the design of slotless PM machine used in drone at ALVA Industries.
- Details to enable the panel to gain access to the output, if required (for example, a DOI or URL):
https://www.ntnu.edu/documents/139952/1313219428/Summary+of+Masters+Theses+2022.pdf/0eda7180-58c0-8b77-d54d-78834b5a9f66?t=1683534731235
[Not yet available as link on NTNU Open]

4
- Author(s): Matteo Leandro
- Title: PhD thesis - "Framework for Analytical-based Digital Twin Development of Electric Drive Using Slotless PM Machines"
- Year of publication: 2023
- Type of output and other relevant details required to identify the output (for example, DOI, journal title and issue): Relevant for the design of slotless PM machine used in drone at ALVA Industries.
- Details to enable the panel to gain access to the output, if required (for example, a DOI or URL):
NTNU Open: Framework for Analytical-based Digital Twin Development of Electric Drives Using Slotless PM Machines

5.
- Author(s): Mikkelsen, Eirik Kvåle; Matveev, Alexey Vyacheslavovich; Nøland, Jonas Kristiansen
- Title: " High-Speed MW-Class Generator with Multi-Lane Slotless Winding for Hybrid-Electric Aircraft"
IEEE Access. 2023, 11 . 10.1109/ACCESS.2023.3302772

4. Details of the impact (indicative maximum 750 words)

This section should provide a narrative, with supporting evidence, to explain:

- How the research underpinned (made a distinct and material contribution to) the impact
- The nature and extent of the impact

The following should be provided:

- A clear explanation of the process or means through which the research led to, underpinned or made a contribution to the impact (for example, how it was disseminated, how it came to influence users or beneficiaries, or how it came to be exploited, taken up or applied).
- Where the submitted administrative unit's research was part of a wider body of research that contributed to the impact (for example, where there has been research collaboration with other institutions), the case study should specify the particular contribution of the submitted administrative unit's research and acknowledge other key research contributions.
- Details of the beneficiaries – who or what community, constituency or organisation has benefitted, been affected or impacted on.
- Details of the nature of the impact – how they have benefitted, been affected or impacted on.
- Evidence or indicators of the extent of the impact described, as appropriate to the case being made.
- Dates of when these impacts occurred.

The technology basis used in the electric machines at ALVA; *Ironless slotless permanent motor technology*, is a result of research done at NTNU/EIL, EME in the years 2012 to 2022.
The awareness of this research ongoing in close vicinity to the NTNU Entrepenørskolen, was a contributing factor for the students and founder(s) of ALVA, to realize this could be a suitable technology for their vision for ALVA.
Utvikler verdens beste dronemotor i Trondheim - Tu.no

Impact employees: Employees in 2022 ca 30

Products:

ALTUS X60 Uno - ALVA Industries – ALTUS X60 Uno

ALVA Industries – ALTUS X60 Duo

X60-Kv120: **ALVA Industries – X60-Kv120**

5. Sources to corroborate the impact (indicative maximum of ten references)

Name, Company	Role	Email
Jørgen Selnes	Founder & CEO	jorgen@alvaindustries.com
Alexey Matveev	Research & IP Director	alexey@alvaindustries.com

[NTNU / IE-Faculty / IEL Institute / Group: EMESP] [case No 3]

Institution: NTNU
Administrative unit: IEL-EMESP
Title of case study: Local sharing of energy and flexibility in distribution grids
Period when the underpinning research was undertaken: 2019-2021
Period when staff involved in the underpinning research were employed by the submitting institution: 2014-
Period when the impact occurred: 2017-2022

1. Summary of the impact (indicative maximum 100 words)

During the last years, there has been a public discussion on how to incentive renewable energy development among electricity end-users and how to utilize the flexibility potential of batteries and shiftable electricity demands. The energy regulation (and grid regulation) has been traditional and old-fashioned as it did not take energy sharing benefits into account, leading to limited realization of said potentials. Our research has shown, through theory and application, that energy sharing has benefits for the individual end-users and for society. By intensive dissemination activities trough different influential channels, the research has increased the awareness of the need improved regulations, eventually leading to changes in the energy regulation in "the right direction" in October 2023.

2. Underpinning research (indicative maximum 500 words)

The directly relevant research has primary been conducted as part of the FME "Zero Emission Neighbourhoods" (FME: Norwegian Research Centre for Environmental-Friendly Energy). This research centre has local energy sharing as one of several focus areas. One particular paper stands out as most influential. The paper "Helping end-users help each other: Coordinating development and operation of distributed resources through local power markets and grid tariffs", published in Energy Economics, made a significant impact, as it analysed in detail how the society can benefit from energy sharing. This article is the result of a cooperation between the EMESP group (Magnus Askeland, Sigurd Bjarghov, Magnus Korpås) SINTEF Energi (Magnus Askeland) and NTNU-IØT (Stian Backe). It also makes use of knowledge gained in other projects and centres, such as FME CINELDI (Sigurd Bjarghov, Magnus Korpås) and the EU project CityxChange (Pedro Crespo del Granado, Magnus Korpås, Stian Backe, Asgeir Tomasgard). As stated in the Phd thesis of Magnus Askeland: "*Based on cost efficiency under decentralised decision-making and the requirement that grid pricing structures should not be excessively complicated, the research includes assessments on how the regulatory framework can be adapted to facilitate optimal solutions on a multi-stakeholder level. This includes both how to incentivise the appropriate amount and location of DERs and how to facilitate favourable operational patterns on an area level.*"

Research period: 2017-2022

Researchers involved:

- Magnus Askeland (Institute-Phd, NTNU-IEL and SINTEF Energi)
- Magnus Korpås (Professor, NTNU-IEL. Main supervisor of M Askeland)
- Sigurd Bjarghov (Phd-candidate, NTNU-IEL)
- Stian Backe (Phd-candidate, NTNU-IØT and SINTEF Energi)
- Asgeir Tomasgard (Professor, NTNU-IØT)
- Pedro Crespo del Granado (Associate prof., NTNU-IØT)
- Karen Byskov Lindberg (Associate prof., NTNU-IEL , and researcher SINTEF Community)

- Annemie Wyckmans (Professor, NTNU Architecture)
- Eivind Junker (Associate prof., Nord Univ)
- Lars Arne Bø (Senior advisor, SINTEF Community)

3. References to the research (indicative maximum of six references)

Magnus Askeland, Stian Backe, Sigurd Bjarghov, Magnus Korpås, "Helping end-users help each other: Coordinating development and operation of distributed resources through local power markets and grid tariffs", Energy Economics, Volume 94, 2021, 105065, ISSN 0140-9883, https://doi.org/10.1016/j.eneco.2020.105065.

Magnus Askeland, "Policy issues for distributed energy resources as a part of larger energy systems", Doctoral theses at NTNU;2022:229, 2022, https://hdl.handle.net/11250/3013082

Magnus Askeland, Stian Backe, Sigurd Bjarghov, Karen Byskov Lindberg, Magnus Korpås, "Activating the potential of decentralized flexibility and energy resources to increase the EV hosting capacity: A case study of a multi-stakeholder local electricity system in Norway", Smart Energy, Volume 3, 2021, 100034, ISSN 2666-9552, https://doi.org/10.1016/j.segy.2021.100034

Eivind Junker, Magnus Askeland, Lars Arne Bø, «Bestemmelser om energi- og miljøkrav i reguleringsplaner – i lys av konseptet nullutslippsnabolag», Tidsskrift for eiendomsrett, 17(2), pp. 108-139, 2022, doi:10.18261/tfei.17.2.2

4. Details of the impact (indicative maximum 750 words)

The research, conducted by former Phd candidate Magnus Askeland (EMESP), supervised by Magnus Korpås (EMESP) with internal and external collaborators, aimed at identifying optimal strategies for local energy sharing, both from the viewpoint of the individuals (profit maximization of each actor) and the society (cost minimization of the grid company). Through theoretical derivations and practical case studies, we showed how grid tariffs and trading strategies could be formed to optimize utilization of solar power and flexible demand under realistic market limitations. Together with other related work in the EU-project CityxChange and FME ZEN, the novel research was disseminated in several public meetings and media channels. The timing was important, as there were an ongoing process at the national level on revising rules and regulations for utilization of solar power from end-users. A key success factor of the dissemination of the research result was to collaborate closely with key stakeholders in the local energy development sector for a common outrearch strategy: Trondheim Kommune, Trøndelag Fylkeskommune, Volue, Skanska, and NTNU Arcitecture.

The collaborative effort resulted in many media reports which help to bring awareness about the benefits of energy sharing. The main dissemination result was a consolation response to «Meld. St. 36 (2020–2021) Energi til arbeid – langsiktig verdiskaping fra norske energiressurser», with the title (translated): «The need for changing the energy regulation», which was sent to the Norwegian Parliament late 2021. This document, and related media reports and meetings, help to create an awareness and an understanding that it was necessary to make it easier for end-users to share their energy resources locally. Eventually, the government decided to change the energy regulation to make it easier and more beneficial to share self-produced power locally (New regulation from Oct 1st, 2023 (https://www.regjeringen.no/no/aktuelt/fastsetter-

forskriftsendringer-for-deling-av-egenprodusert-fornybar-strom-pa-samme-eiendom/id2975877/).

Selected dissemination activities:

- "Behov for endring av energiregelverket", Consulation response signed by Rita Ottevik (Ordfører Trondheim), Tore O Sandvik (Fylkesordfører Trøndelag), Anne Borg (Rektor, NTNU) Berit Rian (adm dir, Næringsforeningen I Trndheimsregionen), Magnus Korpås (EMESP) and others, 28.09.2021. https://www.ntnu.no/documents/1276519421/1279270617/Policy+brief+-+Behov+for+endring+av+energiregelverket+-+08.+sept+2021.pdf/97168e35-765a-92fa-e838-66e5ebfcf035?t=1633682080885 (Attachment 1).
- «Behov for å endre energiregelverket for å fremme det grønne skiftet», Presentation for Strømnettutvalget, 24.11.2021. (Attachment 2)
- «Mekanismer for realisering av mulighetene i desentralisert fleksibilitet», Presentation at the public arrangement Klimafrokost in Trondheim, 27.10.2021 (Attachment 3).
- «Insitamenter for energifleksibilitet i nabolag», Presentation at the public arrangement Klimafrokost in Trondheim, 27.10.2021 (Attachment 4).

5. Sources to corroborate the impact (indicative maximum of ten references)

- Klaus Livik, Previously Chief Strategist, Volue
- Torger Mjønes. Trondheim Fylkskommune
- Marit Myrstad, Previously at Trondheim Kommune
- Svein Nassvik, Chief Advisor, Skanska
- Knut Samdal, research director, SINTEF Energi AS. Knut.Samdal@sintef.no
- Annemie Wyckmans, Professor, Leader of EU-CityxChange, NTNU Architecture.
- Asgeir Tomasgard, Professor, Leader of TSO Energy, NTNU IØT

NTNU, Department of Marine Technology 1

Institution: NTNU
Administrative unit: Department of marine technology
Title of case study: Fostering Entrepreneurship and Shaping the Future Business Landscape of Autonomous Ships
Period when the underpinning research was undertaken: 2014 - present
Period when staff involved in the underpinning research were employed by the submitting institution: Asgeir Sørensen – Professor. Director AMOS – 1999 – present Ingrid Bouwer Utne – Professor – 2009 – present Øyvind Smogeli - Adjunct Professor – 2021 – present
Period when the impact occurred: 2019 - present

1. Summary of the impact

Validation of engineering solutions through functional prototypes and innovative concepts for safety assurance of autonomous ships has been developed through collaborative research with key contributions by researchers from department of marine technology. Basic research, applied research, and prototypes has contributed to new business ventures and innovative models for safety assurance directly relevant for new services provided by suppliers of autonomous ship solutions and an international classification society.

2. Underpinning research

Autonomous ships are expected to improve safety and efficiency and reduce the environmental impact at sea. Reduced human operator intervention, and the gradual absence of personnel onboard, makes it important to develop a sufficient situational awareness both for the autonomous ship and for the operators on land. Autonomy requires advanced control systems and applications with sophisticated algorithms for decision-making under uncertainty. This can lead to safer and more efficient systems and operations, but also to increased complexities and dependencies that are very challenging to identify, analyse, and control in risk management.

A variety of research topics are relevant for autonomous ships ranging from sensor fusion, situational awareness, risk management, control strategies, and integration of ship and shore control. System insight requires a cross-disciplinary approach. This has been accomplished due to the Norwegian centre of excellence, the NTNU centre for Autonomous Marine Operations and Systems (AMOS) which was operational in the period 2013-2023. The research centre was instrumental for cross-disciplinary research connecting resources from department of marine technology, engineering cybernetics, electronic systems, and department of design (**S1**).
The interest in R&D on autonomous ships increased from 2014, with the opening of the Trondheimsfjord as a new national test facility for autonomous vehicles and ships. The research done at NTNU AMOS on autonomy has been both timely and highly relevant. Some key contributions are development of a novel methodology to automate and formalize simulation-based testing of autonomous ships (**R5**) and a new framework for online risk modelling for autonomous ships (**R1**).

As fundamental research in AMOS found application opportunities, new associated projects formed and contributed to enhanced and goal-oriented research. Online risk management and risk control for autonomous ships (ORCAS, 2018-2022) focused on developing safe and smarter automatic sailing systems and power and propulsion systems that are able to detect, verify,

monitor, control, and follow up deviations and potential hazards to improve the situation awareness and decision-making ability of the autonomous ship. Specifically, the research results will lead to improved automatic sailing systems and power and propulsion control systems through the integration of risk modelling, machine learning, simulation, and verification of safe responses with optimization-based model predictive control (**R5**).

The primary goal of the project "Assuring Trustworthy, Safe and Sustainable Transport for All" (TRUSST, 2020-2024) is to "innovate an integrated assurance framework that transforms a complex and interdependent system of people, technology, organizations and the natural environment into a trust ecosystem, that in turn unlocks the potential for testing, deploying and scaling up autonomous passenger vehicles in society" (**R4**). This research will be supplemented by recently initiated research into a holistic and efficient development, testing, and verification strategy with the integrated use of simulations, deploying multiple test platforms combining multiple test methodologies (SIMPLEX, 2023-2025).

The design and construction of physical testbeds in way of the small autonomous ferries milliAmpere1 and 2 (built in 2017 and 2020, respectively), funded by NTNU, was instrumental for the experimental work (**R6**). Furthermore, NTNU has funded research activities related to milliAmpere1 and 2 through the Digital transformation project Autoferry. This work was also supported in part by the Research Council of Norway through projects 296694 (aFerry, 2019-2020), 223254 (AMOS), and 309230 (SFI Autoship, 2020-2028). The milliAmpere1 served as a catalyst in the research and development on control allocation (**R2**), risk indicators (**R3**), and design of the shore control infrastructure, making abstract requirements become specific requirements for land-based supervision.

References to the research (indicative maximum of six references)

R1. Ingrid Bouwer Utne, Børge Rokseth, Asgeir J. Sørensena, Jan Erik Vinnem, 2020. Towards supervisory risk control of autonomous ships. Reliability Engineering & System Safety 196, https://doi.org/10.1016/j.ress.2019.106757

R2. Torben, T.R., Brodtkorb, A.H. & Sørensen, A.J, 2022. Control Allocation for Double-ended Ferries with Full-scale Experimental Results. International Journal of Control Autom. Syst. 18, 556–563. https://doi.org/10.1007/s12555-019-0658-4

R3. Chuanqi Guo, Ingrid Bouwer Utne, 2022. Development of risk indicators for losing navigational control of autonomous ships. Ocean Engineering. https://doi.org/10.1016/j.oceaneng.2022.113204

R4. Tobias Rye Torben, Øyvind Smogeli, Jon Arne Glomsrud, Ingrid B. Utne, Asgeir J. Sørensen, 2023. Towards contract-based verification for autonomous vessels. Ocean Engineering. https://doi.org/10.1016/j.oceaneng.2023.113685

R5. Tobias Rye Torben, Jon Arne Glomsrud, Tom Arne Pedersen, Ingrid B Utne and Asgeir J Sørensen, 2023. Automatic simulation-based testing of autonomous ships using Gaussian processes and temporal logic. Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability;237(2):293-313. doi:10.1177/1748006X211069277

R6. Edmund F Brekke et al, 2022. milliampere: An autonomous ferry prototype. J. Phys.: Conf. Ser. 2311 012029. DOI 10.1088/1742-6596/2311/1/012029.

R7. Skjølsvik, K.O., Kaloudis, A, 2023. Innovating the Innovation System Thinking: a Systemism Model. Journal of Knowlegde Economy. https://doi.org/10.1007/s13132-023-01561-w

4. Details of the impact

The journey from basic research to impact implies a long chain of research and innovation activities. As research is replaced by development and eventually deployment the stakeholders will change and alternative mechanisms are required to maintain momentum. A well-functioning

innovation system will be imperative for success, and the system must be able to manage the network of stakeholder, the changing processes and provide the required framework and support roles (**R7**). The introduction of autonomous ships represents a challenge far beyond automation of ship functions. As a ship represents a complex physical system on its own, introducing autonomous operation increase this complexity and calls for inter-disciplinary research and co-creation between research institutions, industry, and public authorities. The results and output from the research contribution by researchers from the department of marine technology on solutions for autonomous ships has provided visible short time impact as well as expected additional long-term impact.

Economic impact – fostering entrepreneurship.

A total of 8 spin-offs have been realised based on the collaborative research effort founded in the AMOS research centre (Norwegian Subsea in 2014, Blueye Robotics and Eelume in 2015, ScoutDI and UBIQ Aerospace in 2017, Skarv Technologies and Zeabuz in 2019, and SentiSystems in 2021 (**S1**). By 2023, these 8 spin-offs contributed to a total of 138 new jobs (**S2**).

To illustrate a well-functioning innovation system (**R7**), the spin-off company Zeabus is a representative case (**S3**). Based on cross-disciplinary research, cooperating with department of engineering cybernetics, department of electronic systems, and department of design, an AMOS associated project was formed by NTNU to demonstrate key functionalities in an autonomous urban ferry. The aFerry project (2019-2020) (**S4**) demonstrated the situational awareness and collision avoidance functions of a ferry autonomy system with help of the NTNU prototype milliAmpere in the Trondheim canal. The results of this project lay a foundation for further development of regulations and assurance of autonomous passenger ferries. On the commercial side, the project analysed and verified the global market potential, developed branding and partner strategies as well as a business plan for the newly created NTNU spin-off company Zeabuz. NTNUs Technology Transfer Office licensed the NTNU project results to Zeabuz and attracted a senior founding team, later followed by further investment in Zeabuz by Norway's largest transportation company Torghatten ASA. The first commercial route with the new technology solution was put into service in Stockholm in June 2023 (**S5**) under the brand Zeam (Zero Emission Autonomous Mobility). The mission of Zeam is to create an environmentally and economically sustainable mobility concept on water in urban environments. With fully electric propulsion in combination with solar panels, an emission-free service that minimally burdens the power grid is realised. Autonomous driving will also eventually contribute to economic sustainability – making it possible to launch new routes that can connect districts and give urban life better flow (**S6**).

Around the globe, urban areas are growing, and estimates show that more than 70% of the world's population will live in cities by 2050. Humans flock to the waterfront, and today 90% of urban areas are coastal. Urban waterways are often perceived as blockers of transportation flow, crossed by bridges and tunnels that become bottlenecks for road-based mobility and consume valuable land areas. These urban waterways, however, represent a vast potential for emission-free, waterborne transport. Varying levels of autonomy and small purpose-built electric vessels will be the key to achieving mobility system qualities such as high availability, redundancy, flexibility, and cost efficiency. This will significantly contribute to better and more efficient use of urban waterways, enabling citizens to increasingly walk, bike, and use other forms of micro-mobility. This will, in turn, allow less use of valuable land areas, less air pollution from road-based urban transport, and more effective use of natural resources. It all starts with developing trustworthy technologies, now under demonstration in Stockholm by Zeam.

Regulatory impact – enabling safety assurance of autonomous solutions

Developing and introducing automated solutions require a parallel development in assurance practices to ensure that safety at sea is ensured at an acceptable level of risk. The lack of regulatory framework is a key barrier for market growth of autonomous shipping. Acknowledging

the inherent lengthy nature of the international regulatory process within the UN International Maritime Organisation (IMO) and the speed at which new technology is deployed, stakeholders expect flag states by partial delegation to classification societies, to bridge the regulatory gap on a national level, until the international regulatory framework is in place (**S8**).
Based on the insight in a new potential concept for safety assurance of autonomous passenger ferries, the THRUSST project (2020-2024), lead by the classification society DNV, was formed to further enhance the concept (**R5**), utilising the NTNU prototype ferry milliAmpere as a case in the project (**R6**). The primary objective of TRUSST is to innovate an integrated assurance framework that takes as point of departure the insight that autonomous transport systems are formed by a complex and interdependent system of people, technology, organisations, regulators, and the natural environment. The safety and security of autonomous vehicles is not simply a matter of avoiding objects in their trajectory. Rather, they must be seen as elements in a wider context, interacting with the natural environment as well as a part of society. The project's integrated assurance framework aims to transform this complex system into a trust ecosystem (**S7**), hereby enabling a functioning marked for the autonomous ship technology platform. This will be a significant contribution to unlocking an estimated marked projected to grow from $5.61 billion in 2023 to $9.87 billion by 2030, at a CAGR of 8.4% during the forecast period (**S9**).

Strengthening the knowledge platform and the innovation system

A secondary impact of the activities and outcomes presented in this case is a strengthened innovation capability of the regional and national innovation system (**R7**). The complementary mechanisms for solution creation (basic research, applied research, and demonstration projects) have resulted in a large amount of scientific publications and research results to be further exploited (**R1-R6, S1**). Technology transfer ensuring utilisation of outcome of the solutions created has worked according to intentions (**S3**). The local knowledge network has been significantly strengthened: a new national industry cluster with 70 partners has been established in 2020 (**S10**), a new research infrastructure has been developed (**R6**) and the network of the innovation system has formed a new long-term research centre on autonomous ships hosted by NTNU and securing continued activity for 50+ researchers in the years to come (2020-2028) (**S11**). Several researchers, postdoctors, PhD candidates, MSc students, BSc students, internship students, and technical employees have taken part in the development of milliAmpere1&2 and related research and represents the essential foundation for further contributions to innovations and society impact in the area of autonomous waterborne transport.

5. Sources to corroborate the impact

S1. NTNU AMOS Centre for Autonomous Marine Operations and Systems, final report 2013-2023. www.ntnu.edu/amos/publications.
S2. www.proff.no
S3. www.zeabuz.com
S4. https://prosjektbanken.forskningsradet.no/project/FORISS/296694
S5. https://maritime-executive.com/article/world-s-first-autonomous-ferry-set-to-begin-service
S6. www.Zeam.se (company mission)
S7. www.dnv.com/feature/autonomous-urban-mobility.html
S8. Core, Cefor, 2018. Maritime autonomous surface ships Zooming in on civil liability and insurance. https://cefor.no/globalassets/documents/industrypolicy/news/mass---zooming-in-on-civil-liability-and-insurance---10-december-2018.pdf
S9. www.fortunebusinessinsights.com/industry-reports/autonomous-ship-market-101797.
S10. www.oceanautonomy.no/
S11. www.ntnu.edu/sfi-autoship

NTNU, Department of marine technology XX [case number]

Institution: NTNU
Administrative unit: Department of marine technology
Title of case study: Realizing Digital Twin Technology for Offshore Slender Structures
Period when the underpinning research was undertaken: 2012 -
Period when staff involved in the underpinning research were employed by the submitting institution: Svein Sævik – Professor. 2009 – present Bernt J. Leira – Professor – 1999 – present Zhen Gao – Professor - 2015 - 2022 Carl M. Larsen – Professor Emeritus– 1975 - 2015
Period when the impact occurred: 2019 - present

1. Summary of the impact (indicative maximum 100 words)

This section should briefly state what specific impact is being described in the case study.

The lifetime of marine risers and dynamic power cables, connecting floaters to seabed infrastructures, is governed by fatigue resulting from wave loads and Vortex Induced Vibrations (VIV). Traditionally, the fatigue life for such structures has been calculated by simplified and conservative approaches, considering the effects from waves and VIV separately. Such approaches cannot be applied for digital twin type concepts because the real life monitored signal will include contributions from all acting loads. Therefore, a new time domain load model has been developed that describe all relevant load contributions simultaneously, with the potential of lifetime update based on monitored data.

2. **Underpinning research** (indicative maximum 500 words)

This section should outline the key research insights or findings that underpinned the impact, and provide details of what research was undertaken, when, and by whom. This research may be a body of work produced over a number of years or may be the output(s) of a particular project. References to specific research outputs that embody the research described in this section, and evidence of its quality, should be provided in the next section. Details of the following should be provided in this section:

- *The nature of the research insights or findings which relate to the impact claimed in the case study.*
- *An outline of what the underpinning research produced by the submitted unit was (this may relate to one or more research outputs, projects or programmes).*
- *Dates of when it was carried out.*
- *Names of the key researchers and what positions they held at the administrative unit at the time of the research (where researchers joined or left the administrative unit during this time, these dates must also be stated).*
- *Any relevant key contextual information about this area of research.*

The new load model mentioned above is a result of long-term research with the overall goal of providing the industry with more accurate lifetime prediction methods that also can support digital twin technologies for future applications. The latter is considered mandatory for effective integrity management of power cables applied in future wind farms where the number of installations will become huge and with a limited number of sensors in the water column due to cost considerations. In 2012, the state of the art related to global response prediction included separate models for waves (in time domain) and VIV responses (in frequency domain), both based on empirical coefficients. The VIV models at that time also included other limiting assumptions such as stationary flow conditions, unidirectional current and linear structural modelling, which deviates significantly from the reality in terms of simultaneously acting floater motions, waves and current where the two latter both vary in time and direction along the water column. In addition,

non-linear structural behaviour (e.g., due to tension variation, riser-soil interaction or slug flow) was not taken into account.

Then, by the PhD research conducted by Mats J. Thorsen in 2012 (**R1**) (supported by a NTNU scholarship), a new modelling concept was introduced based on expanding the time domain Morrison's equation with load terms describing the vortex shedding process and a synchronization model that allows the load to speed up (or slow down) if the load frequency lags behind (or is ahead of) the structural response frequency. The model relies on empirical coefficients generated from the same experimental data base as the frequency domain methods. The model was further developed by PhD students Jan V. Ulveseter (**R2**) and S.W. Kim (**R3**) (NTNU/Korea scholarships). The key point in the model is that the load for a given set of empirical coefficients only depends on the local relative velocity between structure and fluid, whatever source or direction the relative velocity would have, then eliminating the limiting assumptions of the frequency domain methods.

However, the empirical coefficients include uncertainties because they depend on the flow regime. In order to interpret the real response along an actual riser based on monitored data, it is therefore necessary to combine the model with adaptive learning techniques. As part of the NFR project 237929 (SFI Move), PhD student Xu Han investigated different techniques for updating the hydrodynamic parameters of a ship model based on monitored data, in order to realize response based marine operations. These parameters were handled as stochastic variables, applying discrete Bayesian updating to get a best possible fit to monitored data (**R4**). Then, PhD student G. Radhakrishnan further developed the concept by applying a surrogate model concept to speed up the model update computation process (**R5**).

The aforementioned research activities inspired the research group to apply for the NFR project 308832 (PRAI: Predicting Riser-response by Artificial Intelligence) in cooperation with SINTEF Ocean and SINTEF Digital. The project is ongoing and focuses on investigating different alternative algorithms for model updating, hybrid modelling and uncertainty estimation (**R6**).

As part of SFI Move, PostDocs Mats J. Thorsen and N.R. Challabotla in 2019 also reached a major milestone by developing a prototype fully coupled time domain model considering the two-phase riser flow and the VIV load response applied for an ocean mining riser. This is considered to still be beyond state of the art in 2024 (**R7**).

References to the research (indicative maximum of six references)

R1. M.J. Thorsen, S. Sævik, C.M. Larsen, 2014, A simplified method for time domain simulation of cross-flow vortex-induced vibrations. Journal of Fluids and Structures, https://doi.org/10.1016/j.jfluidstructs.2014.04.006

R2. J.V. Ulveseter, M.J. Thorsen, S. Sævik, C.M. Larsen,2018, Time domain simulation of riser VIV in current and irregular waves, Marine Structures, https://doi.org/10.1016/j.marstruc.2018.04.001

R3. S.W. Kim, S. Sævik, J. Wu, B.J. Leira, (2021), Prediction of deepwater riser VIV with an improved time domain model including non-linear structural behavior, Ocean Engineering, https://doi.org/10.1016/j.oceaneng.2021.109508

R4. X. Han, B.J. Leira, S. Sævik, 2021, Vessel hydrodynamic model tuning by Discrete Bayesian updating using simulated onboard sensor data, Ocean Engineering, https://doi.org/10.1016/j.oceaneng.2020.108407

R5. G. Radhakrishnan, X. Han, B.J. Leira, Z. Gao, S. Sævik, 2023, Calibration of high-fidelity hydrodynamic models utilizing on-site vessel response measurements, Ocean Engineering, https://doi.org/10.1016/j.oceaneng.2023.114076
R6. M.L. Andersen, S. Sævik, J. Wu, B.J. Leira, H. Langseth, 2024, Applying Bayesian optimization to predict parameters in a time-domain model for cross-flow vortex-induced vibrations, Marine Structures, https://doi.org/10.1016/j.marstruc.2023.103571
R7. M.J. Thorsen, N.R. Challabotla, S. Sævik, O.J. Nydal, 2019, A numerical study on vortex-induced vibrations and the effect of slurry density variations on fatigue of ocean mining risers, Ocean Engineering, https://doi.org/10.1016/j.oceaneng.2019.01.041

4. Details of the impact (indicative maximum 750 words)

This section should provide a narrative, with supporting evidence, to explain:

- *How the research underpinned (made a distinct and material contribution to) the impact*
- *The nature and extent of the impact*

The following should be provided:

- *A clear explanation of the process or means through which the research led to, underpinned or made a contribution to the impact (for example, how it was disseminated, how it came to influence users or beneficiaries, or how it came to be exploited, taken up or applied).*
- *Where the submitted administrative unit's research was part of a wider body of research that contributed to the impact (for example, where there has been research collaboration with other institutions), the case study should specify the particular contribution of the submitted administrative unit's research and acknowledge other key research contributions.*
- *Details of the beneficiaries – who or what community, constituency or organisation has benefitted, been affected or impacted on.*
- *Details of the nature of the impact – how they have benefitted, been affected or impacted on.*
- *Evidence or indicators of the extent of the impact described, as appropriate to the case being made.*
- *Dates of when these impacts occurred.*

The journey from basic research to impact implies a long chain of research and industrial project activities. In cooperation with SINTEF Ocean, the developed time domain model has been integrated into the 3D non-linear time domain finite element tool RIFLEX as VIVANA-TD (**S1**). VIVANA-TD intends to capture tension variation, geometry changes, pipe-soil interaction, slug flow, multi-directional current conditions as well as evaluating the wave and VIV load contributions in the same simulation, alleviating key limitations in the existing frequency domain prediction tools.

The commercial software development has been part of the Lazy Wave Riser Joint Industry Project (LWR JIP) Phases 1 and 2, (**S2**) with support from Equinor, BP, Petrobras, Subsea7 and Kongsberg Maritime, with a major goal of contributing to increased safety and cost-effective designs of slender marine structures, e.g., power cables, umbilicals, risers and pipelines. The primary focus has been on 1) model validation and 2) improved design practice in order to make VIVANA-TD commercially available to all users.

The LWR JIP Phase 1 work was carried out as a first step from 2019-2021 with the main objective of qualifying VIVANA-TD for industrial use with respect to pure CF (cross-flow) response prediction, in particular for Steel Lazy Wave Risers (SLWRs) for deep sea oil & gas applications. The results included a qualified model with respect to VIV prediction for risers exposed to combined constant current and vessel motions exposed to CF response. As a major milestone, the project resulted in Equinor upgrading the standing of the model to TRL-4 which is "ready for use in project" (**S3**). It was also identified that the combined IL (in-line) and CF load representation is required when modelling more complex load conditions, e.g., 3D currents and wave loads and also

for modelling pure wave loads at small Keulegan–Carpenter (KC) numbers. A roadmap for a Phase 2, was therefore made focusing on further validation under these conditions.

The LWR JIP Phase 2 was carried out from 2021-2023, where the combined IL and CR load model was further tested against experimental data for combinations of steady and oscillatory flows. Good correlation has been found (**S4)** .

As part of the (PRAI project, a second major milestone was reached, where the combined inline IL (inline) and CF load model was found to compare well with real riser monitored data. This was obtained by combing the model with unsupervised learning by applying clustering analysis (**S5)** to identify different load scenarios.

It has also been noted that the frequency variation in space and time noted for VIV type of response is inherited in the time domain formulation, (**R3**) which is a direct result of the applied synchronization model that catches the effect of non-linear structural behaviours automatically. It is therefore no need for additional assumptions related to combining a set of harmonic responses to approximate the time/space sharing, as in the traditional frequency domain VIV prediction tools. This grossly simplifies model applications and the risk for mistakes during modelling and analysis.

A Phase 3 of the LWR JIP Phase 3 is under planning focusing on further validation with respect to combined irregular wave and current conditions and the effect of hysteresis damping relevant for layered structures such as power cables relevant for future wind farms. This is planned to be used as a basis for updating the DnV recommended practice "DNV-RP-C205 Environmental conditions and environmental loads" and making VIVANA-TD commercially available to all users.

The fact that the model is formulated in time domain as an addition to the Morison load, also allows for applying the model to predict Vortex Induce Motions (VIM) of floating wind turbines exposed to current. This enables the inclusion of more terms in the coupled dynamic behaviour which may be important for the prediction of mooring system lifetime. Preliminary tests of the model applied for Hywind Scotland concept has shown promising results (**S6**). Hence the model might be used for other applications in future.

Another KPN, as a follow up of the PRAI project, is under planning where the focus will be on how we can use the monitored data, time domain formulations, artificial intelligence and hybrid modelling to realize accurate algorithms for decision support related to the inspection, maintenance and repair of dynamic power cables for future applications. To realize the Norwegian governmental ambition of 30GW before 2030, will involve thousands of risers (**S7**). With a limited number of sensors available due to cost considerations, active use of monitored data for model update and uncertainty estimations is considered mandatory for obtaining robust and cost-effective installations

The research activity described above has led to 24 journal articles and 24 conference articles so far.

5. Sources to corroborate the impact (indicative maximum of ten references)

S1. https://www.dnv.com/services/vortex-induced-vibration-analysis-vivana-89365
S2. https://www.sintef.no/en/projects/2022/lwr-jip/
S3. Letter from Equinor titled, dated xx.
S4. D. Yin, J. Wu, H. Lie, E. Passano, S. Sævik, G. Grytøyr, M.A. Tognarelli, T. Andersen, R.Igland, D. Karunakaran and C. Gaskill, 2022, Vortex-Induced Vibrations of a Top-

Tensioned Riser in Combined Currents and Waves, International Conference on Offshore Mechanics and Arctic Engineering, https://doi.org/10.1115/OMAE2022-79033

S5. J. Wu, S. Eidnes, J. Jin, H. Lie, D. Yin, E. Passano, S. Sævik, S. Riemer-Sørensen, 2023,Analysis of full-scale riser responses in field conditions based on Gaussian mixture model, Journal of Fluids and Structures, https://doi.org/10.1016/j.jfluidstructs.2022.103793

S6. H. Mørkeseth, 2023, Time Domain Vortex-Induced Motion Prediction of Spar-Type Floating Wind Turbine, https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/3081508

S7. https://www.powermag.com/dynamic-export-cables-help-unlock-potential-of-offshore-wind-power/

Professor Svein Sævik
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12 January 2024

This letter is a response to NTNU's request for Equinor's assessment of the importance and impact of NTNU's research into VIV in general, and the new time-domain tool VIVANA-TD in particular.

Vortex Induced Vibrations, or VIV for short, is a very complex phenomenon. It is a so-called hydro-elastic problem, where the flow pattern around a structure and the structure response are both influencing each other. The driving mechanism is vortex shedding off a bluff body, like e.g. a cylinder.

Vortex shedding has no scale limitations, and acts on all length scales, from the smallest to the largest. Hence, we can observe the effects of vortex shedding on structures ranging from cables with just a few centimetres in diameter, to offshore platforms with columns in the order of tens of meters in diameter. When referring to these problems they are usually split between Vortex Induced Vibrations, which occur in long slender structures like risers or cables, and Vortex Induced Motions (VIM), which occur in large rigid floating structures like offshore platforms or wind turbines. However, they are manifestations of the same physical phenomena.

VIV influences both strength and fatigue loading of offshore structures, and is a potential design driver. As such it has to be treated with due diligence to ensure safe operations of offshore installations. Hence, we are dependent on having deep understanding of the phenomenon, and good numerical tools for assessment and design of our offshore structures.

Historically, there has been close cooperation between Statoil/Equinor and NTNU on the topic of riser responses in general, and VIV in particular. NTNU has contributed to development of key software packages like RIFLEX and VIVANA, and recently to VIVANA-TD. These are software packages that are now maintained by SINTEF, with NTNU still contributing to further research and development. The combination of NTNU and SINTEF creates an intellectual powerhouse for research, innovation and development, which has been paramount for the development of these key softwares for riser/cable design

VIVANA is a classical, frequency domain tool for assessment of VIV of slender structures. Equinor uses it for design of risers, and for validation and bencmarking of other VIV tools in the market (SHEAR7, VIVA, etc). These classical, frequency domain based tools, have strict limitations in their application, since the problems have to be linearized before being solved in frequency domain. This has traditionally led to some artificial fatigue hot-spots that are purely numerical in nature. Most notably the seabed touch down area of a steel catenary riser. This may in some cases have led to overly conservative designs, and potentially unnecessarily costly mitigating measures to reduce the VIV response. However, we have not had tools available to consistently treat this particular problem. Our hope is that the new tool VIVANA-TD can alleviate this situation. The recent development of VIVANA-TD, which is a new time domain tool, is a potential game changer for VIV design. The reason being that it is integrated

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with the fully non-linear tool RIFLEX. This opens up to include important non-linearities in the systems, e.g. non-linear pipe-soil interaction.

It is almost impossible to assess the potential economic impact of this research at NTNU. The reason being that the potential consequence of VIV is e.g. riser rupture, which in turn leads to potential for blow-out and oil spill. This will have severe environmental consequences, as well as social and economic impact. It can influence fisheries, fish-farming, beaches, tourism, etc. VIV is also an important issue for the renewable industry, with potential structural failure of electrical cables for offshore wind, thus terminating electricity production.

The level of conservatism for a specific design is based on consequences of failure and uncertainty of design methodology. For VIV the present state-of-the-art design tools have relatively high level of uncertainty, and the consequences of failure are severe. Our designs have to be accordingly conservative in order to ensure integrity and safety of offshore facilities. Improved design methodologies and design tools for VIV has a significant economic up-side since VIV mitigation is inherently expensive. NTNU is contributing to both sides of this equation. They have provided tools and methodologies that allow us to do conservative design. In addition they are continuously working to improve the tools, thus increasing confidence in them, allowing us to optimize design without compromizing on safety.

In Equinor we have recently done a technology assessment of VIVANA-TD and qualified it to TRL4 (Technology qualified for first use) for analysis of VIV in steady state 2D current. This matches the capabilities of the traditional frequency domain tools, i.e. VIVANA and SHEAR7. In additiont, NTNU, SINTEF and Equinor has made attempts at using VIVANA-TD to assess VIM of floating wind turbines. The initial tests have been very promising, however more research is required in order to validate this functionality.

The current qualification level, and the future expansion of qualification envelope of VIVANA-TD is strongly dependent on contributions from NTNU. We see the PRAI KPN project as a potential key-contributor to this research and development. The use of AI is inventive and has potential to establish new methods, like e.g. stochastic treatment of VIV; and better empirical parameters for use in assessment of VIV.

VIV has to be understood and treated in a consistent manner to ensure safe design and operation of offshore structures. Hence, it is important to have in-depth understanding of all aspects of the phenomenon, including underlying physics, methods for predicting VIV response, understanding of oceanographic processes that generate the ocean currents, load response, cross section response, damping, drag amplification, and material properties, including both metallic and polymer materials. Due to the severe consequences of VIV, it is also important to be able to suppress the vortex shedding and avoid resonant response of the risers. This requires in-depth knowledge of hydrodynamics, hydroelastic phenomena, CFD (numerical methods), model-testing, (prototyping, 3D printing). NTNU is contributing to key research within all these areas. Hence, the importance of NTNU's research to the field of VIV and fatigue is much larger than just VIVANA-TD.

Yours sincerely,

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NTNU, Department of marine technology

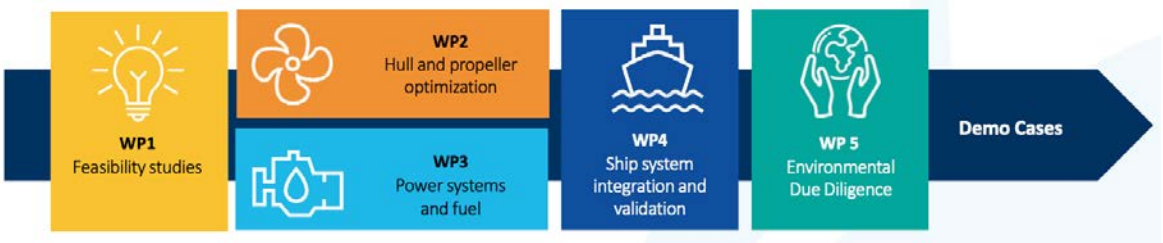
Institution: NTNU and SINTEF
Administrative unit: Department of marine technology
Title of case study: Research-based innovations towards improved energy efficiency and reduced harmful emissions from the maritime sector (SFI Smart Maritime)
Period when the underpinning research was undertaken: 2014 - 2023
Period when staff involved in the underpinning research were employed by the submitting institution: Sverre Steen – Professor, Head of department – 1999 – present Stein Ove Erikstad – Professor – 2008 – present Mehdi Zadeh – Professor – 2015 - present Lars Erik Holmedal – Professor – 2007 - present Eilif Pedersen - Professor – 2005 – present
Period when the impact occurred: 2015 - 2023

1. Summary of the impact

SFI Smart Maritime has worked closely with the most important players in the Norwegian maritime industry with pushing the state-of-the-art within maritime research disciplines. The project has developed insight on emission reductions from ships, developed and tested innovative technology solutions, developed prediction models for hydrodynamics and power systems simulation, and simulation tools for performance evaluation and benchmarking of ship designs. The efforts in the SFI have been instrumental for the Norwegian maritime industry's research-based initiatives towards reducing GHG emissions from shipping.

2. Underpinning research

The research activity is conducted in collaboration between SINTEF Ocean, NTNU and the Centre's 21 partners representing the entire maritime value chain: ABB, Bergen Engines, DNV, Jotun, Kongsberg Maritime, HAV Design, Norwegian Electric Systems, Siemens-Energy, VARD Design, Wärtsilä Moss, the Norwegian Shipowner association, the Norwegian Coastal Shipowners Association, the Norwegian Maritime Authority, and 8 major Norwegian ship owners; BW Gas, Grieg Star, Höegh Autoliners, Klaveness, Kristian Gerhard Jebsen Skipsrederi, Odfjell Tankers, Solvang and Wallenius Wilhelmsen.

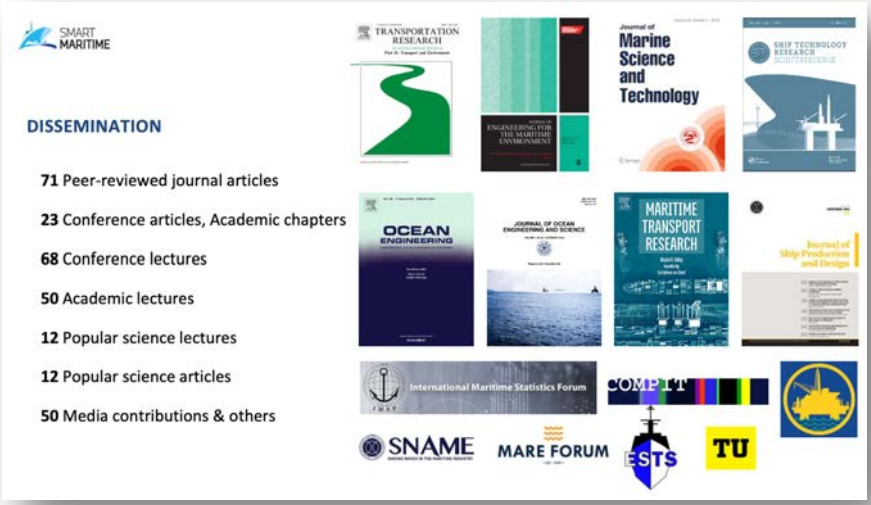


The research covers five interconnected research areas. WP1 serves as screening work package for identifying and assessing potential technologies and designs. There is a lack of assessment methods and tools to enable comparison of alternative designs at the feasibility stage of the design process. Current studies and state-of-the-art design practice regarding concept, speed and capability tend to be based on marginal improvements of existing designs and solutions instead of challenging today´s practice. One explanation is that most vessels for the merchant fleet have

been built by shipyards according to quite standardized designs to minimize building cost while more specialized vessels generally have been improvements and amendments of existing designs.

WP2 and WP3 respectively develop models and tools for assessment of technologies and designs. WP2 covers hull and propeller optimization, by identifying potential for energy savings related to hull and propulsion and introduces novel approaches to improve efficiency. In WP3, the focus is on power systems and fuel, to improve current designs and explore new technologies, systems and solutions for energy efficient low- and zero-emission power systems and improve the autonomy and reliability of power system.

These models are further integrated into a ship system simulation platform, enabling the virtual design and optimization of a ship by numerical simulation model (WP4). This holistic system-centred ship design method uses a modular simulation and analysis framework for accurate performance assessment under realistic full-scale operational conditions. Finally, hybrid LCA methods are used in combination with profit and opportunity cost models to verify environmental and economic benefits (WP5). There is a need for detailed harmonized environmental and economic assessment of current and novel ship designs. In addition, there is a lack of suitable approaches for integration of such assessments with ship design and engineering workflows. WP5 will integrate state of the art methods for detailed climatic, environmental and economic analyses, primarily through the development and analysis of a fleetwide emission model – MariTEAM (R2).



References to the research (indicative maximum of six references)

R1. **Benjamin Lagemann**, Sotiria Lagouvardou, Elizabeth Lindstad, **Kjetil Fagerholt**, Harilaos N. Psaraftis, **Stein Ove Erikstad**, *Optimal ship lifetime fuel and power system selection under uncertainty (2023),* Transportation Research Part D Transport and Environment*,* *DOI: 10.1016/j.trd.2023.103748*

R2. Diogo Kramel, Helene Muri, Young Rong Kim, Radek Lonka, Jørgen B. Nielsen, Anna L. Ringvold, Evert A. Bouman, Sverre Steen, and Anders H. Strømman. *Global Shipping Emissions from a Well-to-Wake Perspective: The MariTEAM Model (2021)* Environmental Science and Technology. Vol. 22. https://doi.org/10.1021/acs.est.1c03937

R3. Lagemann, Benjamin; Erikstad, Stein Ove. *Modular Conceptual Synthesis of Low-Emission Ships (2020). 12th Symposium on High-Performance Marine Vehicles*. Technische Universität Hamburg-Harburg 2020. ISBN 978-3-89220-718-4. p. 134-151

R4. Sandvik, Endre; Nielsen, Jørgen Bremnes; Asbjørnslett, Bjørn Egil; Pedersen, Eilif; Fagerholt, Kjetil. *Operational sea passage scenario generation for virtual testing of ships*

using an optimization for simulation approach. Journal of Marine Science and Technology 2020, DOI: https://doi.org/10.1007/s00773-020-00771-0

R5. Ghimire, P.; Park, D.; Zadeh, M.; Thorstensen, J.; Pedersen, Eilif. *Shipboard Electric Power Conversion: System Architecture, Applications, Control, and Challenges* (2019). IEEE Electrification Magazine. vol. 7 (4). **DOI:** 10.1109/MELE.2019.2943948

R6. Nielsen, Jørgen Bremnes; Sandvik, Endre; Pedersen, Eilif; Asbjørnslett, Bjørn Egil; Fagerholt, Kjetil. (2019) *Impact of simulation model fidelity and simulation method on ship operational performance evaluation in sea passage scenarios*. Ocean Engineering. vol. 188. https://doi.org/10.1016/j.oceaneng.2019.106268

4. Details of the impact

The impact of the SFI is here summarized along five dimensions:

I-1. Regulatory impact – contributing to the IMO framework for ship emission reductions
I-2. Strategic impact on research field
I-3. Impact on ship emissions and the environment
I-4. Impact on the research capacity of Norway related to zero and low emissions shipping
I-5. Economic impact for research, industrial and academic partners

I-1: Regulatory impact – IMO

Throughout the project, international cooperation on the regulatory framework and policy development has been a core topic in network meetings, webinars and as an integrated part of the research (**R2**). Concrete examples of these activities are the contributions to the IPCC International Panel on Climate Change, with Prof. A. H. Strømman and Dr.Helene Muri (NTNU) serving as co-author for the IPCC's Sixth Assessment Report (**S5**), Chief-scientist Elizabeth Lindstad serving the European Shipping Sustainability Forum as expert advisor, contributor and task-lead for working groups on alternative fuels and ship energy efficiency, coordinating submissions to IMO and ISO. SFI Smart Maritime participants, coordinated through the project, have been actively involved in IMO consultations, either through the Norwegian delegation or international forums and industrial initiatives.

I-2: Strategic impact on research field

The SFI has had a leading influence on the strategic research policy development in Norway throughout the period, forming the future research path on sustainability and emission reduction related to shipping.

- Leading working groups in both Martim21 iterations
- Board member in EU public private partnership for Waterborne Transport
- Providing feedback on several government propositions and strategy documents (e.g. Maritim stortingsmelding, Regjeringens strategi for grønn skipsfart)
- Contribution to High Level Panel for a Sustainable Ocean Economy in 2019

I-3: Impact on the emission and the environment

Through the SFI itself, and the associated spin-off projects, the industry partners have implemented emission reduction technologies that have contributed to reduced emissions of greenhouse gases. Some examples are Odfjell´s installation of multifuel fuel cells on their product

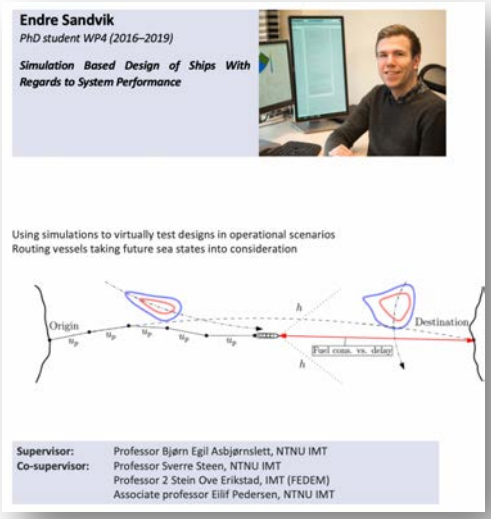
tankers (**S6**), Solvang´s installation of carbon capture and storage (CCS) on their ethylene vessel Clipper Eos (**S2**)

I-4: Impact on the future research capacity of Norway

The SFI will have a lasting impact on the research capacity of Norway towards low and zero emission shipping, not the least through the education of a large number of PhD and PostDoc´s that will start working in industry, in academia, or with research organizations.

In total, the SFI has financed 4 PostDoc projects and 14 PhD projects. In addition, 20 PhD have been in associated projects, as well as 45 MSc students doing their thesis work related to the project.

Below are first two examples of PhD projects, and then a list of all names and project titles.



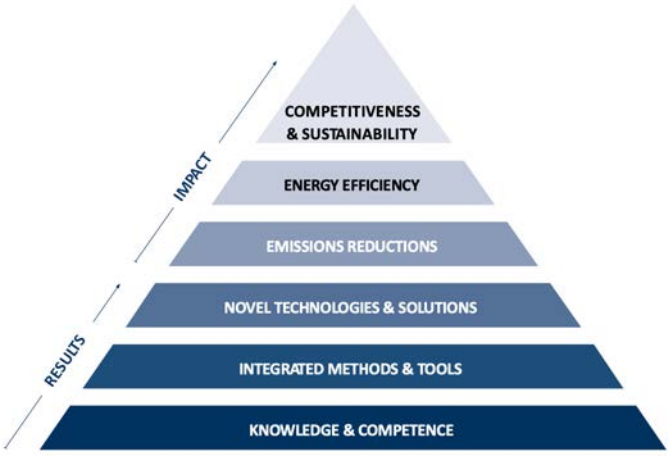
Name	Nationality	Period	Topic
Postdoctoral researchers SFI Smart Maritime			
L.Prasad Perera	LK	2015 – 2017	Data handeling and analysis
Torstein I. Bø	NO	2015 – 2018	Hybrid propulsion
Renato Skejic	HR	2016 - 2018	Computation of added resistance due to waves
Dražen Polić	HR	2020 - 2022	Impact of wind propulsion on the propeller and power system. (WP3)
PhD students SFI Smart Maritime - WP2 Hull and propeller optimization			
John Martin Godø	NO	2015-2018	Hydrodynamics
Jon Coll Mossige	NO	2017-2020	Added resistance on ships due to hull roughness
Prateek Gupta	IN	2018–2022	Ship performance monitoring using in-service measurements & big data analysis
Ehsan Esmailian	IR	2019-2022	Optimization of ships for operation in real sea states
Jarle Kramer	NO	2020-2022	Hydrodynamic modelling of wind-powered merchant vessels
PhD students SFI Smart Maritime - WP3 Power systems and fuels			
Jørgen Nielsen	NO	2015-2018	System simulation
Vladimir Krivopolianskii	UA	2015-2018	Fuel injection and combustion
Kamyar Maleki	IR	2019-2022	A Simulator Approach to Concept Analysis and Optimization of marine Power Plants
Yuan Tian	CN	2020-2023	Modelling and simulation of ship exhaust gas cleaning system
Siamak Karimi	IR	2019-2022	Modelling and optimal design of marine hybrid electric power systems
Marius Ulla Hatlehol	NO	2021-2024	Modelling, Design and Control of Hybrid Electric Power and Propulsion
PhD students SFI Smart Maritime - WP4 Ship System Integration and Validation			
Endre Sandvik	NO	2016-2019	Simulation Based Design of Ships
Benjamin Lagemann	GE	2019-2022	Concept Ship Design for Future Low-Emission Shipping Technology

In total, the SFI has produced more than 80 journal publications, see full reference list (**S4),** plus a number of conference papers, magazine articles, etc.

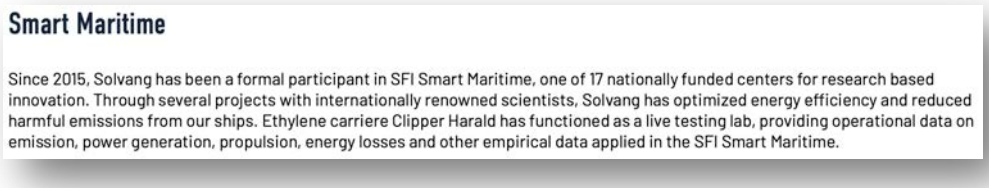
I-5: Economic impact

Throughout the whole centre period, the industrial partners have focused on utilization of the research results through innovation. The main categories of innovations taken into use by the industry are:

- New technology and products for green ship power systems and emission abatement
- New methods for ship and system design
- Software tools for vessel design simulation and evaluation
- Innovative and energy-efficient ship designs built for several ship owners
- Improved business services based on simulation-based design processes
- Testing and verification of new green ship technology
- Establishment of spin-off projects and companies



From Solvang´s web site describing the impact on their business (S2):



Smart Maritime

Since 2015, Solvang has been a formal participant in SFI Smart Maritime, one of 17 nationally funded centers for research based innovation. Through several projects with internationally renowned scientists, Solvang has optimized energy efficiency and reduced harmful emissions from our ships. Ethylene carriere Clipper Harald has functioned as a live testing lab, providing operational data on emission, power generation, propulsion, energy losses and other empirical data applied in the SFI Smart Maritime.

Further, the HAV group has integrated the results from the SFI into their OceanLab virtual environment, improving their value creation and competitive position in a demanding market; "*This tool is a result of many years of systematic R&D work. It is unique in a commercial context, giving our customers the possibility to develop simulation-based concepts. ... This, combined with the HAV Group's cross-cutting expertise, means we can create vessels with the best energy and operational efficiency, giving our customers a head start and increased value creation." (S8)*

Several of the innovations developed through the SFI period have happened through the dedicated spin-off projects. One example of this is the ZeroCoaster modular coastal vessel developed by VARD (**S3**), in which a new modular coastal ship design was developed. The full list of associated projects is shown below:

ASSOCIATED PROJECTS

Project title	Period	Funding	Smart Maritime Partners
HOLISHIP - HOLIstic optimisation of SHIP design and operation for life cycle	(2016-2020)	EU H2020	Kongsberg Maritime, DNVGL, SINTEF
Hybrid testing - Real-Time Hybrid Model Testing	(2016-2020)	MAROFF, KPN	NTNU, SINTEF
SATS - Analytics for ship performance monitoring in autonomous vessel	(2018-2020)	MAROFF, KPN	NTNU, SINTEF
Open simulation platform	(2018-2020)	JIP	DNV GL, Kongsberg Maritime, SINTEF, NTNU
Digital twin for lifecycle operations	(2018-2022)	MAROFF	DNV GL, Kongsberg Maritime, SINTEF, NTNU
CLIMMS - Climate change mitigation in the maritime sector	(2019-2023)	MAROFF, KPN	NTNU, SINTEF, Rederiforbund + all 8 ship owners SFI-partners
SmartShipRouting	(2019-2021)	MAROFF, IPN	NCS, NES, Havila, Havyard, SINTEF
RuteSim: Simuleringsbasert Ruteplanlegging	(2019-2020)	MAROFF, IPN	Grieg Star, WWO, KGJS, SINTEF, Nansen
Digital twin yard	(2019-2021)	MAROFF, IPN	DNVGL, Rolls-Royce, NTNU, SINTEF
FreeCO2ast	(2019-2022)	PILOT E	Havyard, Havila , SINTEF
Extension of Hybrid Lab	(2019-2019)	ABB	ABB, SINTEF
Autoship	(2019-2022)	EU H2020	Kongsberg, SINTEF
RedRes - Innovative surface structures to reduce friction	(2020-2023)	MAROFF, KPN	JOTUN, SINTEF, NTNTU, Grieg Star
IPIRIS - Improving Performance in Real Sea	(2020-2023)	MAROFF, KPN	VARD, Havyard, Kongsberg, SINTEF, NTNU
CruiseZero – Zero-emission expedition cruise	(2020-2022)	MAROFF, IPN	VARD, ABB, SINTEF
PEZOS - Plug-In Electric Zero-emission Offshore-ship	(2020-2022)	MAROFF, IPN	VARD, SINTEF
Bio4-7seas - Biofuels in deep sea shipping for climate change mitigation	(2020-2023)	ENERGIX, KPN	NTNU, SINTEF
ZeroCoaster - Zero-emission coastal bulk shipping	(2020-2022)	MAROFF, IPN	VARD, ABB, DNV GL, SINTEF
Air-lubrication	(2020-2022)	MAROFF, IPN	Jotun, SINTEF
Gaters	(2020-2022)	EU H2020	Strathclyde, SINTEF
Aegis	(2020-2023)	EU H2020	SINTEF
VesselAI	(2021-2024)	EU H2020	Kongsberg, SINTEF
CCShip – Carbon Capture and Storage onboard ships	(2021-2024)	MAROFF, KSP	Klaveness, Wärtsila, NCCS, Calix,SINTEF, NTNU
AMAZE - Ammonia zero emission	(2021-2023)	MAROFF, IPN	Bergen Engines, SINTEF, NTNU
SEA-Co - Safer, easier and more accurate Co-simulations	(2021-2025)	MAROFF, KSP	DNV, Kongsberg, SINTEF, NTNU
ISTS - Intelligent ship transport systems	(2021-2024)	MAROFF, KSP	SINTEF, Kongsberg, DNV, Grieg, Kystverket, Sjøfartsdirektorate
ZeroKyst – Decarbonization of ships for seafood sector	(2021-2024)	Green Platform	Siemens, SINTEF, NTNU
ProfSea - Ship Operational Performance in Following Sea	(2021-2024)	NFR, KSP	Kongsberg, SINTEF, NTNU
Ecorouter - Route optimization integrating low-carbon technologies	(2022-2024)	MAROFF, IPN	KGJS, OSM, Odfjell

5. Sources to corroborate the impact

S1. SFI Smart Maritime Final Report 2023. https://www.smartmaritime.no/main/shortcuts/about-smart-maritime/
S2. https://solvangship.no/feature_article/a-long-voyage-towards-discovery/
S3. https://maritime-executive.com/article/norwegian-design-for-green-ammonia-fuel-cell-coaster-receives-approval
S4. https://www.smartmaritime.no/documentation/publications/
S5. https://www.ntnu.edu/indecol/international-panels/intergovernmental-panel-on-climate-change
S6. https://www.odfjell.com/about/our-stories/fuel-cell-project-develops-ground-breaking-fuel-solution-for-ships-and-offshore/

S7. https://prosjektbanken.forskningsradet.no/en/project/FORISS/282184?Kilde=FORISS&distribution=Ar&chart=bar&calcType=funding&Sprak=no&sortBy=date&sortOrder=desc&resultCount=30&offset=60&TemaEmne.2=Annen+miljøteknologi
S8. https://www.havdesign.no/hav-design/hav-ocean-lab/

NTNU, Department of Marine Technology 4

Institution:	**NTNU**
Administrative unit:	**Department of Marine Technology**
Title of case study:	**Implementation of research-based marine technology education for improved interaction between aquaculture industry and academia: "Bridgehead Aquaculture 2050"**
Period when the underpinning research was undertaken: 2012- Ongoing	
Period when staff involved in the underpinning research were employed by the submitting institution: 2018 - Ongoing	
Period when the impact occurred: 2012 - 2022	

1. **Summary of the impact** (indicative maximum 100 words)

"Bridgehead Aquaculture" (Brohode Havbruk in Norwegian) is a multi-stakeholder regional knowledge platform to strengthen the innovation ability of the aquaculture sector. Increased relevance in education is created through facilitating interactions between marine engineering students educated on a research-based knowledge base at (among others) the IMT department, vocational schools, and experts in aquaculture companies throughout the study programme. The use of interactive meeting places, case studies, and applied student projects, with interdisciplinary supervision of IMT researchers from various marine engineering disciplines, stimulates the application of enabling technologies and engineering competence in a sector facing biological and environmental challenges. Its vision is to deliver high-quality university candidates, with competence based on the research front of aquaculture science covered by several disciplines, directly contributing to strengthening the aquaculture sector's capacity to achieve resilience, sustainability, and competitiveness. Based on the platform activity, two new study programs have been developed: a bachelor in aquaculture engineering and a minor in aquaculture. In both programmes, IMT researchers have contributed.

2. Underpinning research (indicative maximum 500 words)

The goal of Bridgehead Aquaculture is to enhance the aquaculture sector's capacity to implement resilience, sustainability, and competitiveness with regional stakeholders as key enablers. A knowledge gap analysis undertaken in 2018 showed the sector's challenge to recruit technology and engineering competence. The aquaculture sector also misses opportunities by not maximizing the potential of high-tech solutions as steppingstones towards the above-mentioned goals. An understanding of the impact of new technologies and production methods on the health and welfare of aquaculture species and on the marine environment is hereby critical. Bridgehead Aquaculture 2050 has contributed to increased knowledge and human capacity to apply new technologies, whilst setting biology in the centre, leading to smarter, greener and more efficient processes.

Since the signing of cooperation agreement between NTNU Oceans and the secondary "blue" school of Guri Kunna (Hitra/Frøya) in 2012, an annual Bridgehead conference has been organized at Frøya. This has become a unique meeting place for aquaculture stakeholders and academia, where students and IMT researchers fulfill a key role as representatives of their capacity building abilities. The agreement was renewed in 2021.

In addition to the annual conference, a series of Bridgehead meeting places are organized throughout the year. These vary in form, ranging from experience exchange seminars, company site visits, business presentations, workshops, student competitions and/or speed date sessions. The events stimulate stakeholders in the region to increase their network and to implement

student projects and marine engineering research into their business strategies. The project specifically accentuates the underexploited capacity of interdisciplinarity across engineering and enabling technologies, biology and other natural and social sciences, and humanities. By stimulating interactions between stakeholders and academia, a common understanding of the various processes along the aquaculture value chain is established, where academia can contribute with research-based knowledge for a further sustainable development of this industry.

The Bridgehead aquaculture 2050 toolbox helps introducing research-based competence through different pathways. It has introduced a considerable number of companies to the opportunities provided by an industry PhD and has assisted many of them in applying. It has also engaged industry stakeholders at IMT as lecturers, case suppliers and in part-time positions, promoted mobility of NTNU professors through short-term stays in a company and organized visits for researchers to different types of aquaculture businesses. These interactions have additionally contributed to increase the societal relevance of education and research among academic partners, and to attract candidates towards a sector where Norway has a global responsibility.

The Norwegian Research Council's mid-term evaluation in 2021 highlighted the progress that had already been made in the creation of a knowledge-based capacity-building legacy in the region of Mid-Norway.

Key researchers (positions) joined:

- Alexandra Neyts, Project leader
- Bjørn Egil Asbjørnslett, leader of “minor in aquaculture” education programme.
- Pål Lader, project collaborator.
- Kjell Olav Skjølsvik, innovation manager.

3. References to the research (indicative maximum of six references)

1. Olavsen T, Winther U, Skjermo J Olsen Y .
   DKNVS and NTVA Report: Value created from productive oceans in 2050
   2012
   ISBN 978-82-7719-074-3
   The report makes prediction of future development of the seafood sector in Norway and conclude that the value created in 2050 can be 550 billion NOK, five times higher in 2050 than in 2010. The report has had a tremendous impact on society and policy formation in the seafood sector, but also on the scientific community. The report is generally simply mentioned as the “2050 report” and is very frequently sited. It is still after 10 years among the planning documents used by Government, and an implementation plan is worked out after request of the Department responsible for fishery. if requested by RCN or the evaluation secretariate.
2. Neyts, A., Heggstad, T., Fallmyr, J.,
   2018
   Kartlegging av kompetansebehov i Midt-Norge.
3. Neyts, A.
   Which professional profiles does the aquaculture industry need and which educational paths are missing or need to be improved?.
   2022
   Aquaculture Europe '22; 2022-09-27 - 2022-09-30
4. Neyts, Al., Vedal, T.,
   Årsrapport Brohode havbruk 2050 – år 5.
   2023

5. Akslen Emblem, H. L., Halstenrud, K. B.
NTNU Brohode Havbruk. En kvalitativ analyse av kommunikasjon og forventninger i et samarbeid mellom havbruksnæringen og akademia. Prosjektoppgave i MV3010 Forskningsoppdrag for bedrift.
2021

4. Details of the impact (indicative maximum 750 words)

In 2018, a consortium of academia (NTNU, SINTEF Ocean), industry (NCE Aquatech Cluster, Blue Competence Centre), and public sector (Trøndelag County Authority) was formed, and the Norwegian Research Council granted a 6-year collaborative capacity-building project "Bridgehead Aquaculture 2050". Its goals are to increase business relevance in higher education, strengthen recruitment to the marine sector, and reinforcing research-based expertise in the seafood industry. Through this Bridgehead Aquaculture 2050 project, a toolbox is developed to close the gap between students, researchers, and aquaculture stakeholders. New study programs have been developed (see below), aquaculture relevant student cases and assignments have been promoted, and mobility efforts between academia and industry have contributed to a larger mutual understanding. The annual Bridgehead conferences strengthen the collaborative culture in aquaculture across stakeholder groups with a specific emphasis on the academic knowledge base, the students, and their knowledge-building capacity.

Recommendations by and dialogue with the sector resulted in the generation of a unique aquaculture engineering bachelor programme in 2020. It prepares the students for a professional career in the producing and supplying industry, providing them with knowledge on state-of-the-art and deeper insights on how technology and operational choices impact the efficiency and sustainability in aquaculture. A pilot programme package for Master of Technology, called "Minor in aquaculture" was established in 2021. This allows the students to combine their technological expertise with a basic understanding of biology and aquaculture operations, thus introducing new types of knowledge into the sector. IMT has had a central role in both study programs, delivering specific courses on aquaculture technology, design and operations, organizing training sessions to acquire practical skills, and case studies. Marine technology science and competence is at the heart of developing a research-based education towards candidates with a high relevance for developing the sector further according to sustainability principles.

An increasing share of students is performing bachelor and master assignments and PhD theses in aquaculture related topics. In 2023, 156 student assignments were delivered, across more than 20 different study programmes. Back in 2018, the same number of assignments was 69. Of the total of 665 student assignments and PhD theses in the period 2018-2023, 173 were related to mechanical engineering and marine technology.

Upskilling of existing staff was also targeted by developing and offering continued education courses at Master level. So far, three courses have been established (on recirculating aquaculture systems, on safety management and risk analysis, and on project management and engineering in aquaculture), with the one on safety management being developed at IMT.

In 2016 the project *"Taskforce salmon lice" – cooperation between university and aquaculture industry to solve salmon lice challenges"* – was established as a direct result of this impact case.

"Bridgehead Aquaculture" is at the core of several United Nations sustainable development goals (SDGs), particularly;

- Goal 3 - Ensure healthy lives and promote well-being for all at all ages
- Goal 4 – Quality education, ensuring inclusive and equitable quality education and promote lifelong learning opportunities for all

- Goal 8 - Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
- Goal 9 - Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation
- Goal 11 - Make cities and human settlements inclusive, safe, resilient, and sustainable
- Goal 14 - Life below water. Conserve and sustainably use the oceans, seas and marine resources for sustainable development
- Goal 17 - Strengthen the means of implementation and revitalize the global partnership for sustainable development

5. Sources to corroborate the impact (indicative maximum of ten references)

Brohode Havbruk - NTNU

Studentoppgaver: Projects | Bridge NTNU

NTNU Brohode – Minor i havbruk – NTNU

Bachelor i ingeniørfag, havbruk - NTNU

NTNU Brohode - Brohodekonferansen - NTNU

Taskforce sea lice - NTNU Oceans - NTNU

5.1 Impact cases

NTNU IIR

Institution: Norwegian University of Science and Technology (NTNU)
Administrative unit: Institutt for IKT og realfag (IIR)
Title of case study: Co-simulation technology for digital twins
Period when the underpinning research was undertaken: 2017-2021
Period when staff involved in the underpinning research were employed by the submitting institution: 2017-2021
Period when the impact occurred: 2021-present

1. Summary of the impact

Co-simulation is crucial for digital twins because it enables a more comprehensive and accurate representation of complex systems and processes. Many systems involve interactions across multiple domains, such as mechanical, electrical, thermal, and fluidic. Co-simulation allows the integration of different simulation tools that specialize in these domains, enabling a holistic representation of the entire system. By combining various simulation models with specialized accuracy in different aspects of a system, co-simulation improves the overall accuracy of the digital twin. This is particularly important for systems where the interaction between different components significantly influences the system's behaviour.

2. Underpinning research

The maritime industry is undergoing a transformative phase, marked by a pressing demand for innovation and efficiency across operations, life cycle services, and the design of maritime systems. With modern vessels increasingly operating autonomously and relying on strongly interacting sub-systems, there is a need for a sophisticated approach to their design, operation, and integration. The complexity of engineering tasks related to vessel life cycle services is further intensified by the intricate mutual interactions among on-board sub-systems, each dedicated to specific primary objectives or essential ship operations. The seamless exchange of data and coordinated decision-making by these sub-systems, ideally without user interaction, poses a formidable challenge that demands an efficient development approach. Digitalization emerges as a key catalyst for innovation and efficiency in the maritime industry. However, the sheer diversity of modelling tools across disciplines necessitates a careful consideration of integration challenges, including issues related to heterogeneous systems, hardware, and resource utilization. Implementing complex-cyber-physical systems, such as vessels, in a monolithic or centralized manner is deemed undesirable due to associated drawbacks. Co-simulation emerges as a pivotal solution, allowing different sub-systems to be independently modelled yet simulated collectively. This technique facilitates the distributed modelling and running of various sub-systems, each acting as a simulator. Co-simulation's key advantage lies in its ability to enable users to simulate models exported from different tools in a unified manner, promoting reusability, model sharing, and the fusion of simulation domains. Expanding the scope of co-simulation into the realm of digital twins involves incorporating real-world sensor data into the models. A digital twin, defined as a virtual representation of a physical asset enabled through data and simulators, empowers real-time prediction, optimization, monitoring, controlling, and informed decision-making. The digital twin serves as a proxy for the physical world, allowing estimation of a vessel's performance before conducting real-world tests, thereby offering flexibility and significant cost reductions. This research, which was conducted

between 2017-2021, aimed to promote the adoption of co-simulation standards and the development of use cases by providing user-friendly software. The goal includes offering enabling technology for building standard-conforming models and systems, along with subsequent tools for simulating them. The presented case studies demonstrate the effectiveness of this approach, paving the way for enhanced practices in co-simulation and digital twin development within the maritime industry.

The research endeavour was a collaborative effort between Lars Ivar Hatledal, who was a PhD student at the time and has since become an Associate Professor at IIR, and Associate Professor Arne Styve. This joint undertaking was part of a larger project titled "Digital Twins for Vessel Life Cycle Service."

3. References to the research

- **LI Hatledal**, **A Styve**, G Hovland, H Zhang, A language and platform independent co-simulation framework based on the functional mock-up interface, *IEEE Access*, vol. 7, pp. 109328-109339, 2019.
- **LI Hatledal**, R Skulstad, G Li, **A Styve**, H Zhang, Co-simulation as a fundamental technology for twin ships, *Modeling, Identification and Control*, vol, 41 (4), pp. 297-311, 2020.
- **LI Hatledal**, Y Chu, **A Styve**, H Zhang, Vico: An entity-component-system based co-simulation framework, *Simulation Modelling Practice and Theory*, vol. 108, no. 102243, 2021.
- H Zhang, G Li, **LI Hatledal**, Y Chu, AL Ellefsen, P Han, P Major, R. Skulstad, T. Wang, H. P. Hildre, A Digital Twin of the Research Vessel Gunnerus for Lifecycle Services: Outlining Key Technologies, *IEEE Robotics & Automation Magazine*, vol. 30, pp. 6-19, 2023.

4. Details of the impact

The main impact of this research is the contribution to the development of Open Simulation Platform (OSP): https://opensimulationplatform.com/.

OSP is an open-source industry initiative for co-simulation of maritime equipment, systems and entire ships. With steadily increasing complexity due to the increasing use of software in ship systems, the integration of equipment and systems from many providers and a gap in systems engineering traditions, the consequence is apparent: It has become increasingly difficult to design, build, operate and assure ships and other maritime/offshore assets, and to balance cost with environmental footprint and safety. The OSP sets out to change this by providing the maritime industry with key tools and working processes for technical systems engineering, enabling efficient and effective construction and maintenance of digital twins for system integration, testing and verification.

Building on the Functional Mockup Interface (FMI) standard, the key principles are to:

- Enable the re-use of simulation models and digital twin equipment across organizations without exposing sensitive IP by protecting models and control system software inside black-box executables.
- To establish a standard for connecting models and control systems from any simulation tool or programming language in one, large co-simulation to enable virtual system integration.
- To enable cross-organization cooperation and platform interoperability by transparency and open-source principles.

The primary contributions of our work encompass the facilitation of the System Structure and Parameterization (SSP) standard, alongside the implementation of distributed model execution. This was achieved through the integration and seamless transition of the proxy-FMU software package. Furthermore, our involvement extended to the development of a Java port for libcosim.

5. Sources to corroborate the impact

OSP is used by DNV for design of maritime hybrid systems. Video:
https://www.youtube.com/watch?v=a2YCEgwtY2c&ab_channel=KevinKoosupYum

OSP conference in 2022 can be seen here:
https://www.youtube.com/playlist?list=PLN2MU6GHu5J8kFsWUlsdfjAbql9hhM3IZ

NTNU IVB 1

Institution: NTNU
Administrative unit: IVB
Title of case study: Intelligent Bolted Joints
Period when the underpinning research was undertaken: 2018 - 2020
Period when staff involved in the underpinning research were employed by the submitting institution: One Professor 2010 – now and 2 PhD/Postdoc researchers between 2013 – 2020.
Period when the impact occurred: 2020

1. Summary of the impact

Bolt connections are commonly used structural fasteners in many types of industries including mechanical, aerospace and civil engineering. Bolts are fastened to maintain specific preloads during service to ensure the safety and reliability of structures. However, in many structures, maintaining the primary preload might be difficult due to external impacts (such as wind force) resulting in high vibrations followed by reduced tension which loosens the bolt connections. Periodic maintenance of the multipoint bolts is thus crucial for proper operations and avoidances of structural failure. This impact case describes an efficient and cost-effective wireless sensor solutions for monitoring bolted connections. The system has been developed in collaboration with Dokka Fasteners AS, one of Europe's largest fasteners manufactures.

2. Underpinning research

We have developed a wireless enabled intelligent bolted joints for automatic monitoring of preload [**R1**]. The monitoring system can be used for preventing accidents (warning if a bolt is broken, loosened, etc.) and improved maintenance cycles where re-loading only the bolted joint that needs it. The novel aspect of the system is the development of power efficient, radio integrated, load-sensing intelligent bolted joints for long-term and large-scale monitoring of critical infrastructure. This is important as current monitoring methods are highly time-consuming and expensive involving regular manual operations for checking and maintaining the bolt preloads. We have developed an accurate bolt looseness detection method utilizing a load-sensor with integrated radio transceiver for wireless transmission of the bolt preload [**R1**]. The key research challenges have been to design a load-sensor that can accurately measure the bolt preload under varying conditions (i.e., wide range of temperature, humidity, and pressure). Selecting the signal signature to be used (peak frequency shift, frequency transfer function, phase shift, magnitude, etc.). identifying the influencing factors on the accuracy of the sensor, and identifications of any hysteresis effect in the loading/unloading process. In addition, we have designed an energy-efficient, low-cost miniature radio transceiver [**R2**] capable of operating in structures with harsh wireless propagation conditions [**R3**] [**R4**]. The main research challenge in this regard has been to optimize the sensing instances, for power conservation, where the sensor sampling is initiated only after a given pre-load threshold is exceeded. This must also be optimized with the amount of pilot signals transmitted by the wireless strander to minimize the power usage.

Once the preload is measured, the data must be sent to a central unit for monitoring. To use wired connections for multipoint bolt joints is both unpractical and costly. Recently, wireless solutions for structural health monitoring are emerging. However, existing wireless solutions use off-the-shelf radio transceivers with relatively large areas resulting in the overall system (including the power source, load sensor and the radio transceiver) to be bulky, too large to be integrated on the bolt joint components. Part of the research has been to design a compact design that can be easily integrated at e.g., the bolts head. In addition, the reliability of existing wireless solutions in harsh structural wave propagation environments (such as in wind turbines, oil and gas installations, cranes, etc.) is not known. This is very important, as engineering structures are generally known to

be radio harsh environments with significant wave propagation impairments. Thus, part of the research also focused on characterizing the radio propagation characteristics in harsh propagation environments [**R3**] [**R4**].

The following were the key researcher at the department for carrying out the research:

1) Professor Michael Cheffena, employee at the unite from 2010 – now.
   Website: https://www.ntnu.no/ansatte/michael.cheffena
2) Yun Ai was a PhD student and later a postdoc at the department from 2013 -2020 under the supervision of Prof. Michael Cheffena.
3) Marshed Kassim Mohamed was a PhD student and later a postdoc at the department from 2015 -2020 under the supervision of Prof. Michael Cheffena.

3. References to the research

[R1]: Wireless Sensing System, Patent Cooperation Treaty (PCT), WO2021140135 - January 7, 2021. https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2021140135&_cid=P20-KXHKJU-57255-1

[R2]: M. Mohamed, M. Cheffena, Y. Ai, and A. Al-Saman, "Buffer delay improvement in gait-cycle-driven transmission power control scheme for WBAN", IEEE 31st Annual International Symposium on Personal, Indoor and Mobile Radio Communications, 31. August 2020 – 03 September 2020, London. **DOI:** 10.1109/PIMRC48278.2020.9217071

[R3]: Y. Ai, J. B. Andersen, and M. Cheffena, "Path-loss prediction for an industrial indoor environment based on room electromagnetics", IEEE Transactions on Antenna and Propagation, vol. 65, Issue 7, pp. 3664-3674, May 2017. **DOI:** 10.1109/TAP.2017.2702708

[R4]: M. Cheffena, "Propagation channel characteristics of industrial wireless sensor networks", IEEE Antenna and Propagation Magazine, vol. 58, Issue 1, pp. 66-73, February 2016. **DOI:** 10.1109/MAP.2015.2501227

4. Details of the impact

The research contributing to the impact is done in close collaboration with Dokka Fasteners AS, which is a company located in Dokka, Oppland, Norway that manufactures special fasteners up to M100 for wind power, oil and gas installations, cranes, and heavy engineering structures (such as wheeled mining vehicles, large conveyor, massive power plant or any heavy-duty applications). The company has been producing fasteners for more than 140 years. It is the only one of its kind in Norway and one of the largest manufacturers of fasteners in Europe with customers and deliveries worldwide. As of January 2017, Dokka is a qualified supplier for 8 out of 10 of the top wind turbine manufacturers in the world. The company aims to further develop its products utilizing new enabling technologies. The use of wireless enabled intelligent bolt joints for structural monitoring would give the company huge competitive advantage on a global scale which in turn will positively affect the region in terms of knowledge and sustainable economic development, employment, and wealth creation. The wind energy industry is still a heavily growing market with large untapped potentials, according to all projections and market studies available. In Dokka Fasteners business model, the target is to stay "*The world's most innovative and automated manufacturer of fasteners*". Intelligent bolt joints can also add to other services like distribution centers abroad which are located near customers, container kit packing, vendor managed inventory/kanban to original equipment manufacturers, electronic data interchange integration, technical engineering, a FastTrack program for after-market, service and maintenance needs, etc. The Wurth Group has supported Dokka Fasteners with capital for investment and growth since its acquisition of Dokka Fasteners in 2008, with e.g., heavy automatization, organization competence development.

The wind industry has an enormous growth potential. According to data from 2017, less than 5% of total energy production comes from wind, and the projection is that the percentage can increase to 19% in 14 years. Dokka Fasteners is in a very good position, with a well-established brand recognized as one of the handful companies today trusted with special fasteners for wind assemblies 100 – 200 meters above the ground, off-shore installations, etc. and serves all the largest 4 wind turbine manufacturers, including Siemens, Vestas and Goldwind. Deliveries today are made directly to wind farm construction sites in Africa, Australia, America in addition to Europe, and Dokka Fasteners ambition is to be able to deliver in absolutely all parts of the world where wind energy is installed. Though Dokka Fasteners is one out of the 4 European suppliers to wind projects of large special fasteners, nevertheless Dokka Fasteners market share is still not more than 10% of the world market, and the ambition is to outgrow the general wind market growth and attain 15-20% of global market share. The intelligent bolted joints innovation would spearhead the image of Dokka Fasteners and secure the company a unique market position further upon the above-mentioned long established brand recognition and technical and logistical capabilities. As Dokka Fasteners already has a lot of automation, further growth mean extension of plant facilities and number of employees, contributing to the regional development.

4. Sources to corroborate the impact

1) https://www.ntnutto.no/prosjekter-items/dokka-smart-bolt/
2) https://gemini.no/2018/05/selvtenkende-bolter-a-hindre-ulykker/
3) https://www.ntnutto.no/av-og-til-er-det-kort-vei-fra-grunnforskning-til-produksjon/
4) https://www.forskning.no/energi-ntnu/selvtenkende-bolter-for-a-hindre-ulykker/1120907
5) https://www.regionaleforskningsfond.no/innlandet/nyheter/smart-bolts/
6) https://www.alt.no/5-35-1022322

NTNU IVB 2

Institution: NTNU
Administrative unit: IVB
Title of case study: Geographical Islands FlexibiliTy
Period when the underpinning research was undertaken: 2019 - 2023
Period when staff involved in the underpinning research were employed by the submitting institution2 Professor (2010/2014-now), 2 associated professor(2014/2016-now), one lecturer (2000-now) and 3 PhD/Postdoc researchers between 2019 – 2022.
Period when the impact occurred: 2022

1. Summary of the impact

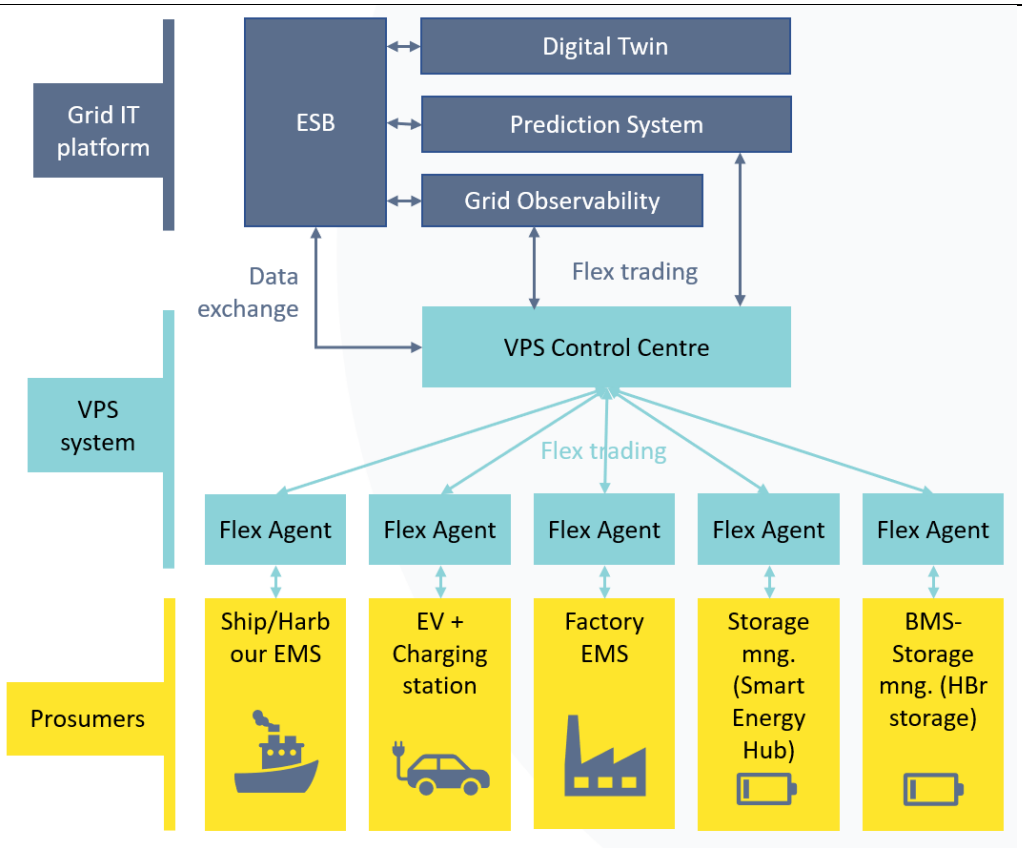
The GIFT project is revolutionizing energy sustainability on inhabited EU islands. Historically reliant on costly fossil fuel imports despite abundant renewable resources like wind and wave energy, these islands are poised to become clean energy innovation leaders. GIFT introduces cutting-edge solutions, including a virtual power system, energy management for various sectors, advanced supply-demand prediction, and GIS data visualization. It also pioneers synergistic storage systems linking electrical, heating, and transportation networks. This project significantly boosts renewable energy usage, curtails diesel dependence, and markedly reduces greenhouse gas emissions, aligning with European and international green energy mandates.

2. Underpinning research

Overview of GIFT's Innovative Solutions:

The GIFT project, targeting the energy sustainability of over 2200 EU islands, has pioneered three main innovations (see figure):

- Components of a grid IT platform for KPI visualisation, geographic digital twin, grid observability, prospective modelling and long-term assessment;
- Parts of a decentralised automatic demand response trading platform connecting DR providers, intermediaries and DR users called the Virtual Power System (VPS), or;
- Prosumers providing flexibility.



Detailed Research Insights of NTNU Team:

NTNU team developed 1) long term energy model, 2) AI based short term energy model, 3) geographic digital twin.

1. Long-Term Energy Model (TIMES-Hinnøya):

Development and Integration: The TIMES-Hinnøya model, developed for Hinnøya Island, Norway, was integrated with the EnergyPLAN electricity system model. This innovative coupling led to the creation of five scenarios to explore the impact of key policy instruments on energy transition [R1-R3].

Collaborative Research with SAP: In collaboration with Sapienza University of Rome, optimization of hydro plants, wind turbines, and PV panels in the Hinnoya region was conducted. The research utilized HOMER software, demonstrating significant cost reductions and GHG emission reductions through renewable energy systems.

2. AI-Based Short-Term Energy Model:

Data Analysis and Impending Commercialization: This model, developed using data from 20 fish farms, accurately predicts energy demand within a 1-48 hour window. With a 95% accuracy rate, it is a critical component of a prediction system on the verge of commercialization.

3. GIS-Based Digital Twin:

Innovative Development and Pilot Testing: The GIS-based digital twin, designed for local DSOs and municipalities, is currently undergoing post-project testing in Hinnøya and Procida. It provides essential data for strategic decision-making, including grid distribution and real-time energy demand.

Research Context and Timeframe:

Conducted over several years, this research reached significant milestones in 2022. It represents a concerted effort by the NTNU team to advance sustainable energy solutions for island ecosystems, aligning with global environmental challenges and technological innovations.

Impact on Policy and Energy Transition:

The long-term energy model TIMES-Hinnøya revealed that achieving net-zero emissions by 2050 is contingent on the adoption of zero-emission vehicles. Additionally, the study on fish farms proposed least-cost decarbonization solutions, highlighting the potential of grid-integrated storage as an optimal investment under certain conditions.

Technological Advancements and Predictive Modeling:

The AI-based model's ability to predict energy demand with high accuracy marks a significant step in energy management, offering a foundation for more efficient and sustainable energy use. Similarly, the GIS-based digital twin presents a new paradigm in energy infrastructure management, potentially revolutionizing how municipalities and DSOs approach energy distribution and consumption.

Collaborative Efforts and Future Directions:

Collaborative efforts, particularly with SAP, have enriched the research, adding a cross-disciplinary perspective. The ongoing discussions around copyright and commercialization highlight the potential for broader application and impact of these innovations in the energy sector.

The following were the key researcher at the department for carrying out the research:

1) Professor Lizhen Huang, employee at the unite from 2014 – now.
   Website: https://www.ntnu.edu/employees/lizhen.huang
2) Professor Alemayehu Gebremedhin, employee at the unite from 2010 – now.
   Website: https://www.ntnu.no/ansatte/alemayehu.gebremedhin
3) Associated Professor Yongping Liu, employee at the unite from 2016 – now.
4) Website: https://www.ntnu.edu/employees/liu.yongping
5) Associated Professor Erling Onstein, employee at the unite from 2014 – now
   Website: https://www.ntnu.edu/employees/erling.onstein
6) Lecturer Sverre Stikbakke, employee at the unite from 2000– now.
   Website: https://www.ntnu.edu/employees/sverre.stikbakke
7) Xu Chen was a postdoc at the department from 2020 -2022 under the supervision of Prof. Lizhen Huang.
8) Dejene Assefa Hagos was a postdoc at the department from 2019 -2021 under the supervision of Prof. Lizhen Huang.
9) Wenji Zhou was a postdoc at the department from 2019 -2021 under the supervision of Prof. Lizhen Huang.

3. References to the research

[R1]: **Zhou, W., Hagos, D. A., Stikbakke, S., Huang, L. *, Cheng, X., & Onstein, E.** (2022). Assessment of the impacts of different policy instruments on achieving the deep decarbonization targets of island energy systems in Norway – The case of Hinnøya [Article]. *Energy*, *246*, Article 123249. https://doi.org/10.1016/j.energy.2022.123249 **(Q1) (IF=8.857)**

[R2]: **Hagos, D. A., Liu, Y., & Huang, L*.** (2022). Investigating alternative power supply solutions under long term uncertainty for offgrid-offshore fish farm: The case of Hinnøya island, Norway [Article]. *Smart Energy*, *7*, Article 100078. https://doi.org/10.1016/j.segy.2022.100078 .

[R3]: **Hoseinzadeh, S., Garcia, D. A., Huang, L.** (2023)**,** Grid-connected renewable energy systems flexibility in Norway islands' Decarbonization, Renewable and Sustainable Energy Reviews, Volume 185, 2023, 113658, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2023.113658. (Q1) (IF=15.9)

4. Details of the impact

1) Contribution of the Long-Term Model to Local Decision Making and Investment Planning:

Impact on Municipal Climate Action and Investment Plans: The long-term model developed by our team has significantly influenced local policy and investment decisions. For example, Harstad Municipality, a partner in the GIFT project, utilized insights from our model to develop its climate

action plan. This led to increased investment in Public EV charging infrastructure and the initiation of new plans for E-ferries.

Influence on Local DSO's Investment Strategies: The model's forecasts prompted the local Distribution System Operator (DSO) to strategically postpone seabed cable investments, aligning them with the projected demand for E-ferries.

2) Short-Term Model's Contribution to Flexibility Trading:

Enhanced Prediction System Features: Our AI and machine learning-driven Enhanced Prediction System offers modular prediction services, focusing on energy demand. Together with partners the tool include energy supply and demand, voltage profiles, grid flexibility needs, demand response sizing, and price forecasting. This system is adaptable to various use-cases and integrates seamlessly with third-party tools.

Advanced Forecasting Capabilities: The system's AI architecture automatically tailors forecasting models to each site, efficiently integrating external data. Its probabilistic scenario generation and stochastic non-convex optimization enhance the robustness of predictions, crucial for managing renewable energy sources, electric vehicles, and fluctuating demand.

3) Digital Twin's Contribution to User-Friendly Operations and Climate Strategy Development:

Grid Operation Advantages: The digital twin for grid operation offers an agile, one-stop solution, easily integrating with existing systems and being adaptable to user needs. It provides comprehensive information on grid status, prosumer behavior, and future projections up to 48 hours.

Framework Flexibility and Stakeholder Information: As an open framework, the GIFT GIS twin can incorporate new elements, offering tailored information for various stakeholders like grid companies, prosumers, and entities involved in VPS and EMS, enhancing operational and strategic decision-making.

Evidence of Impact and Timeframes:

Local Policy and Infrastructure Changes: The direct application of our research in Harstad Municipality's climate action and investment planning illustrates the tangible impact of our long-term model.

Operational Enhancements in Flexibility Trading: The deployment of our Enhanced Prediction System demonstrates its practical utility in energy management and flexibility trading.

Strategic Improvements in Grid Operation: The adoption and integration of our digital twin in grid operations underscore its effectiveness in enhancing operational efficiency and strategic planning.

In conclusion, the research conducted by our team has made substantial contributions to local decision-making, operational efficiency, and strategic planning in energy management. These impacts, occurring from 2021, demonstrate the practical application and significant influence of our research beyond academia.

5. Sources to corroborate the impact

https://www.gift-h2020.eu/

https://www.harstad.kommune.no/

NTNU MTP 1

Institution: Norwegian University of Science and Technology (NTNU)
Administrative unit: Department of Mechanical and Industrial Engineering (MTP)
Title of case study: Seram Coatings – making possible the impossible: thermal spray of Silicon Carbide (SiC)
Period when the underpinning research was undertaken: 2010 – 2014 and onwards
Period when staff involved in the underpinning research were employed by the submitting institution: the whole period until today
Period when the impact occurred: 2010 – today

1. Summary of the impact

This case study deals with the achievement of what was believed to be impossible in the thermal spray industry, i.e., making possible to spray Silicon Carbide (SiC). This has been achieved at our department in the period 2010-2014 within the framework of a PhD project supervised by Prof. Nuria Espallargas. In this PhD project a new chemical process was developed for powder technology dedicated to thermal spray. That chemical process led to the filing of a patent application in 2012. The research culminated in December 2014 with the creation of a start-up company (Seram Coatings AS) that currently commercializes the result of this research under the name *ThermaSiC*. *ThermaSiC* is the first viable Silicon Carbide powder material ever made for the thermal spray market. Until our invention came out, the thermal spray industry stated that materials lacking a melting point (e.g. SiC, Si_3N_4) could not be used due to sublimation (solid-gas transition) during exposure to high temperatures in the spraying process. However, the properties of these types of ceramic materials (high temperature resistance, thermal conductivity, and low weight among others) are very attractive and wanted in this industry. We managed to transform a material that originally lacks a melting point (SiC) to a new material (*ThermaSiC*) that now has a melting point and can therefore be used in the thermal spray industry.

2. Underpinning research

Thermal spray technology was invented and developed by Ulrich Schoop more than 100 years ago (the first patent dating back to 1909). Advances have been made, mostly related to equipment, to the point that this is the technology that enabled more efficient and reliable aircraft turbines in the 1950s. However, in this long history, nobody has been able to overcome the challenge of spraying materials lacking a melting point before our invention came out. This is because, for decades, the powder technology for thermal spray feedstock materials has remained very conservative due to the very strong focus on market. Therefore, our invention has been focused on new powder technology processes based on bottom-up chemical approaches to overcome the challenge of producing “impossible materials” for thermal spray.

SiC is a very interesting engineering material since it is the fourth hardest synthetic material in the world. SiC is produced directly from sand, one of the most abundant materials on Earth and it is inert and non-contaminant. SiC has similar properties to diamond and it is a key material in semiconductors and microelectronics. Among its many properties, the most relevant ones for thermal spray are its high thermal and electrical conductivity, and its light weight, making it a very interesting material for transportation and energy applications. Indeed, bulk SiC materials are used in aerospace, seals for maritime applications, in components for high temperature resistance, in aggressive chemical environments, for wear prevention, etc. Our newly developed chemical process allows the use of SiC in thermal spray

coatings, therefore opening for a significant cost reduction (replacement of expensive bulk SiC materials) and for new applications for the thermal spray market.
This research work therefore involved the merger of two well established technologies, thermal spray, and powder technology. The challenge was to develop a specific chemistry for SiC that would allow this material to be thermally sprayed. This was achieved withing the framework of a PhD project that started in 2010 and ended in 2014 with the PhD defense and the creation of a start-up company (Seram Coatings AS). At the mid-term of this PhD project, the Technology Transfer Office of NTNU (NTNU-TTO) was contacted to explore patent possibilities. In 2012 a patent application was filed with the findings achieved until then. The start-up company was created with the help and encouragement of NTNU-TTO given the market possibilities for the invention. NTNU-TTO were involved in the PhD project in 2012 and they supported all the work related to research and innovation grants that allowed funding the research performed until the end of the PhD project and the establishment of the company (e.g. of funding received between 2012 and 2014 are NTNU Discovery and FORNY2020). Once the company was established funding has been continuously acquired throughout the years via research grants from the RCN and the EU (e.g. SME Instruments Phase II, IPN-BIA, RFF, and others), but most importantly through several innovation prizes (listed below) and private investors that still support the company until today through the board of directors and different investment rounds.

The people involved in this journey were the PhD candidate (Fahmi Mubarok), the PhD supervisor (Nuria Espallargas) and the NTNU-TTO team (many different people that were working at the time at NTNU-TTO).
The main researchers in this case have been involved in this long journey with different roles throughout the years. They are listed below:
Fahmi Mubarok:

- 2010-2014: PhD student, co-founder and co-owner of Seram Coatings AS.
- 2014-2017: innovation postdoc funded 50% by NTNU and 50% by Seram Coatings.
- 2014-2017: R&D leader for Seram Coatings.
- 2017-today: 10% employed at Seram Coatings AS as technical advisor.

Nuria Espallargas:

- 2010-2014: PhD supervisor, co-founder and co-owner of Seram Coatings AS.
- 2014-2018: CTO and board member of Seram Coatings AS, at periods combined with the Prof. position at NTNU (20-50%) to supervise other PhD projects and research.
- 2018-today: board member of Seram Coatings AS, investor, technical advisor as freelance job outside NTNU.

Key dates for this case are: PhD project (2010-2014), company establishment (2014), patent applications (2012 and 2016), investors (2015-today), pilot production established in 2017, customer co-development and qualification tests started in 2018, break during pandemic (2020-2021).
Innovation prizes (winner and finalist):

- 2022: Finalist at the European Inventor Award, SME category, organized by the European Patent Office. Finalists among 500 nominees.
- 2019: Finalist at the EU Women innovators prize. 9 finalists of a total of 180 applicants.
- 2017: Prize to the best female entrepreneur of Norway founding a technology company.
- 2015: Prize to the best young woman entrepreneur of Norway.
- 2015: Seram Coatings AS was awarded the EU Academic Enterprise Award – ACES 2015.
- 2014: Adolf Øien Kapitalfond award to Seram Coatings AS.

3. References to the research

1. *ThermaSiC* patent: https://patents.google.com/patent/WO2014068082A3
2. Article about Seram Coatings and investors in Norwegian newspaper: https://www.dn.no/forskning/grunder/grundervirksomhet/staltro-pa-knallhard-oppfinnelse/1-1-5590787 (translation available here)
3. Article about the innovation breakthrough, focusing on Prof. Espallargas' PhD student and co-founder: https://geminiresearchnews.com/2014/04/silicon-carbide-puzzle-solved/
4. Interview with Prof. Espallargas after winning the award of Female Entrepreneur in Norway in 2017: https://www.tu.no/artikler/nuria-er-blitt-eier-i-en-bedrift-med-enormt-potensial-men-vil-likevel-vaere-forsker-pa-heltid/431798 (only available in Norwegian)
5. Video of Fahmi Mubarok in 2014 when finalising his PhD and we got our first funding (FORNY) to found Seram Coatings AS: https://vimeo.com/93889876
6. Press media from EPO (2022): https://www.epo.org/en/news-events/press-centre/press-release/2022/452185

4. Details of the impact

In terms of market impact, the potential of this invention has been estimated to be more than 1 billion Euros. Our technology can replace conventional coatings and also open up new markets, such as in the additive manufacturing where powder technology is also central. Seram Coatings has many customers with whom we are currently co-developing the product and performing qualification tests (both in EU, Japan and America). The actual companies testing the product cannot be disclosed, but the applications go from transportation (automotive and train), aerospace, turbines, glass production, rolls for steel and paper production, maritime, aluminium production, etc. Since its foundation, Seram Coatings has got great economical support from both the Norwegian Research Council, Innovation Norway, Regional Norwegian Foundation, the EU (H2020 SME-instrument phase 2) and our private investors. This gives us additional motivation to complete this innovation and to succeed as a company. All this has been possible thanks to the expertise and help provided by NTNU-TTO who have been taking the university ideas to the market since 2003. The dissemination process has been performed participating in different innovation events across Norway and the EU, holding continuous meetings with potential customers, attending conferences, industrial events, etc.

As for the beneficiaries, the main ones are of course the founders of Seram Coatings, the investors and NTNU, who are the owners of the technology developed and are in charge of its commercial, scientific and educational exploitation. The application of this invention is mostly intended for civil use. However, the product is generic and can potentially address military use, however this is not in any of the company plans and discussions.

At the time of the foundation of the company (December 2014) there were two employees at 100% (the CEO and a researcher) and two at 50% (Prof. Espallargas and Fahmi Mubarok). Since then, the company has grown to 11 people (all located in Norway) and 1 person (Fahmi Mubarok in Indonesia at 10%). In addition, we hire the services from different advisors (production, technical, market sales). The growth has been fast, but during the pandemic there was a break of several months. In 2019, the pilot production was moved to an industrial area of Norway (Herøya) to further develop the industrialization and commercialization of the invention. All this has been possible thanks to the support of our investors and the good cooperation with our customers. Therefore, the capabilities for job creation and growth both in Norway and the EU and globally are expected to be high.

With the pilot production capacity fully operational and proven in 2018, our short-term strategy is to reach sales of our full pilot production of 5000 kg of material in 2024 to our current list of customers and reach a TRL 9 in at least 50% of the qualification tests we are performing with them. The companies currently testing our pilot product are located in UK, US, Germany, Sweden, Norway, Italy, Poland and Japan. In addition, we have recently (2022)

secured our second research project with the European Space Agency to develop coatings with improved erosion resistance for the exploration of Mars and the Moon.
Our mid-term strategy is to scale up the pilot production to reach a capacity of 24 000 kg and have commodity sales for components at TRL 9. We also plan to set up a pilot line for our second and third products after reaching TRL 4 with both. Our second product was patented in 2016. We will also carefully document and prove the most interesting and highest potential applications for the first product *ThermaSiC.*
Long-term we expect to have applications consuming more than 100 000 kg per year for each of the products. We aim to be a European large player in the thermal spray industry, providing thermal spray powder.
ThermaSiC can change society for the better in several ways. First, it is in a replacement for Tungsten Carbide-Cobalt-Chromium cermet material (WC-CoCr) which is in many cases sourced from conflict areas or areas with child labour and pollution. In addition, Tungsten Carbide is mainly sourced from China. Europe has a strong need for a local replacement and *ThermaSiC* can enable that since the EU produces 13% of global SiC consumption. *ThermaSiC* will also contribute to preserving the environment and health. For example, we are now testing the product in break discs for the automotive and the train industry. Recent research has indicated that brake dust (generated from the wear process of the discs – airborne particles) can bring respiratory problems, but with *ThermaSiC* we have measured less wear than todays´ solutions. Indeed, this will be a requirement in the new EURO7 regulation for automotive emissions. Therefore, the current pilots and initial test results, the company is close to establishing a global footprint in supplying the thermal spray industry with a unique potential of global growth in terms of economy and job creation.

5. Sources to corroborate the impact

See section 3. In addition to those the following can be of interest:

1. Our second patent application for our new upcoming product (MetalSiC): Thermal spraying of ceramic-metallic materials. Nuria Espallargas and Fahmi Mubarok. WO2018033577 A1. PCT/EP2017/070779, priority date 16th August 2016.
2. Yttrium Aluminum Garnet Powder Feedstock for Atmospheric Plasma Spray. Valaker, E.A., Mubarok, F. & Espallargas, N. J Therm Spray Tech 29, 955-966 (2020).
3. Suspension Plasma Spraying of Sub-micron Silicon Carbide Composite Coatings. Mubarok, F., Espallargas, N. J Therm Spray Tech 24, 817-825 (2015).
4. Synthesis of Thermal Spray Grade Silicon Carbide Feedstock Powder for Plasma Spray Deposition. F. Mubarok; N. Espallargas. Proceedings of the International Thermal Spray Conference 2015. Paper No: itsc2015p0689, pp. 689-694 (2015).
5. Tribological behaviour of thermally sprayed silicon carbide coatings. F. Mubarok, N. Espallargas. Tribology International 85, 56-6 (2015).
6. https://www.patentstyret.no/laer-av-andre-liste/seram-coatings/
7. https://www.tu.no/artikler/nuria-er-blitt-eier-i-en-bedrift-med-enormt-potensial-men-vil-likevel-vaere-forsker-pa-heltid/431798

[MTP, DAM] [Impact Case # 2]

Institution: Norwegian University of Science and Technology (NTNU)
Administrative unit: Department of Mechanical and Industrial Engineering (MTP)
Title of case study: NAPIC – NTNU Aluminium Product Innovation Centre
Period when the underpinning research was undertaken: 2016-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2017-present
Period when the impact occurred: 2018-present

1. Summary of the impact

This impact case, NAPIC, is a long-term research centre with the ambition to become a world leader in research-driven aluminum product innovation. Norway produces approximately 1.5 million ton primary aluminium annually, where the majority goes to export. This means there is a huge potential in generating value added manufacturing of aluminium product in Norway. NAPIC is collaboration between NTNU, SINTEF and the Norwegian aluminium industry, covering the crucial triangle for closing the innovation gap from fundamental research towards commercialization. NAPIC leverages and utilizes multi-disciplinary research for systematic product development and innovation, including key deliverables such as; knowledge on aluminum applications for future engineers, methods on how to organize future product development and innovation processes, case studies and demonstrators that promote and increase the use of aluminium, MSc, PhDs and Post Docs trained to solve current and future industrial challenges, and spin-off companies based on commercial utilization of R&D results.

Since the beginning of NAPIC in 2017 more than 20 research projects, spanning from IPNs, KPNs, INFRA, and Green Platform etc, are generated, more than 30 PhD/Postdocs are educated and more than 100 MSc students have been involved across NTNUs departments of Architecture, Product design, Material, Engineering, Manufacturing and Industrial Economy. These research activities have materialized into a series of innovations and impacts through extended collaboration with industry companies (more than 30 companies have been involved), demonstrating innovations within industry sectors such as; Automotive, Maritime, Energy, Infrastructure; Marine. The innovations, examples described later in this document, can be measured in terms of lower cost, higher value, reduced energy consumption, reduced CO_2e footprint, improved quality etc.

For instance, NAPIC has contributed to realize low-maintenance bridges (Hangar-bridge), an all-aluminium battery electric high-speed ferry (Medstraum), more efficient electric conductors for battery systems (Corcus busbars), flexible tooling for advanced metal forming processes in the automotive industry (Benteler), low CO2 bridge utilizing clay-based concrete with post-consumer aluminium reinforcement (Grødøla), high stability roller-skis (IDT Solutions) etc.

2. Underpinning research

Aluminium brings about some properties that are attractive for many applications [1]. It is lightweight (one third of steel), high strength to weight ratio, relatively good conductor of heat and electricity, corrosion resistant, emits low rates light and odor, formable and in principle infinitely recyclable – and the material can be cast, melted, formed, machined and extruded, meaning that it can be manufactured into a variety of shapes and then subsequently fabricated to suit a large variety of uses. Due to its versatility and strength, the use of Aluminium is increasing worldwide, a primary production of about 70 million ton in 2023, where the transport sector is the most demanding sector in terms of tonnage followed by engineering, packaging and electric conductors.

To review high value-added aluminum products, it is essential to consider various aspects such as recycling, production processes, market opportunities, energy efficiency, and maintenance properties. The aluminium industry is increasingly focusing on sustainable practices, including recycling and the development of innovative alloys to reduce environmental impact and improve cost-effectiveness [2]. Furthermore, the development of innovative secondary aluminum alloys has

shown promise in achieving comparable mechanical properties to primary alloys while reducing costs, energy consumption, and CO2 emissions [3]. For instance, utilizing post-consumer aluminium scraps instead of primary aluminum to produce load-bearing automotive components consumes less than 8% as much energy as the first-time production, and emits only about 4% of GHG of primary Al production. Post-consumer Al scraps from the disposal of end-of-life products are environmentally friendly as they can act as "urban mines" to avoid the depletion of natural resources like the bauxite.

Furthermore, aluminum alloys have been extensively researched as structural materials, with a focus on their application in engineering structures [4] - in alignment with the European Aluminum Industry's Sustainability Roadmap towards 2025, emphasizing sustainable development and innovative technologies along the aluminum value chain. This involves research into alloy development, compensation metallurgy, through-process modelling, welding and joining, fatigue properties and forming processes that enables the above. DAMM has focused primarily on the tree last-mentioned properties and challenges when it comes to structural integrity of aluminium. For instance, fatigue [5] (multi-axial high- and low cycle base- and weld material), bending and forming [6] (advanced 3-dimensional stretch forming of aluminium hollows to predict and improve spring-back effects) and joining [7] (solid-state joining to reduce heat affected zone).

DAMM has also conducted research on product development and innovation processes that facilitate material substitution innovation. Aluminium is a young material in the world of structural materials, meaning that the process of introducing aluminium into new markets and uses involve replacing other materials such as steel, concrete, copper, wood and polymer composites. Thus, the innovation process has to address the challenges this scenario brings about [8].

These studies above have been conducted in several research projects from 2015-2022, involving the researchers; Torgeir Welo, Geir Ringen, Jun Ma, Sigmund Tronvoll, Nima Razavi, Filippo Berto, Martin Steinert, Øystein Grong (prof Em), to mention some.

3. References to the research

[1] Kolbeinsen, L. (2020), The beginning and the end of the aluminium value chain, Matériaux & Techniques, 108 5-6, 506, DOI: https://doi.org/10.1051/mattech/2021008.

[2] Soo, V., Peeters, J., Paraskevas, D., Compston, P., Doolan, M., & Duflou, J. (2018). Sustainable aluminium recycling of end-of-life products: a joining techniques perspective. Journal of Cleaner Production, 178, 119-132.

[3] Zhan, H., Zhang, L. Wang, P., Hodges, A., Zhang, Y. and Wang, J. (2022), Transition from earth mining toward urban mining: up-cycling post-consumer scraps to produce automotive grade aluminum extrusions, Materials Today Sustainability, 23, 100462.

[4] Georgantzia, E., Gkantou, M., & Kamaris, G. (2021). Aluminium alloys as structural material: a review of research. Engineering Structures, 227, 111372.

[5] Sarkar, Aritra; Razavi, Nima; Ringen, Geir; Welo, Torgeir. (2023) Assessing the fatigue behaviour of recycled Al-alloys: A critical review. Materialia.

[6] Ma, Jun; Tronvoll, Sigmund Arntsønn; Welo, Torgeir. (2023) Towards Control of Springback Variability in Novel Flexible Stretch Forming of Aluminium Extrusions. Springer Nature.

[7] Tognan, A., Sandnes, L., Totis, G., Sortino, M., Berto, F. and Grong, Ø. (2022), Evaluation and origin of residual stress in hybrid metal and extrusion bonding and comparison with friction stir welding, International Journal of Mechanical Sciences, 218, 107089.

[8] Beste, C., Welo, T., Olsson, N. (2020) Influence of innovation, complexity and newness on success in new product development projects: a survey in Norwegian manufacturing industry, DESIGN Conference.

3. Details of the impact

This part is structured into the following impact cases; Bridges, Ships, Conductors and PCS.

Bridges: Aluminium has been used in bridge structures for decades, tracing back to bridge decks in North America in the early 1930s and the all-aluminium bridge crossing the Saguenay River in Arvida. The first all-aluminium bridge in Norway was the Forsmo bridge, completed in 1996 as a collaboration between Leirvik and the R&D program Expomat. However, no significant breakthrough for aluminium as a bridge material is achieved – at least for long-span bridges. In recent years some efforts are been taken to demonstrate the feasibility of aluminium in such bridges. A project from 2014-2016 reveled aluminium as a well-suitable material for the combined submerged tunnel and artificial sea-bed floating bridge structure for crossing the Sognefjord (1300m). Combining properties such as light-weight, ductility for crashworthiness (ship collisions), formability and visual appearance, the actors Snøhetta, SAPA, Hydro, Statens Vegvesen, Dr Techn. Olav Olsen, Deep Ocean Group and SINTEF made a number of analytic and external oriented prototypes. In 2019 a NAPIC pre-project on exploring aluminium for the Langenuen suspension bridge, a fjord crossing prospect on the west coast of Norway in relation to the ferry-free E39 program, was reported (span of 1235m). This study claimed that the Capex cost figures for the aluminium alternative, meeting all relevant design criteria, is similar to a benchmark steel option. It can be seen that the aluminium bridge girder itself is slightly more costly, but this can be offset by reduced costs for the other main elements: tower, hangers and main cables. Any cost savings from lower maintenance costs and higher recycling potential of using aluminium alloys have not been included.

A broad array of actors and stakeholders were assembled to investigate the feasibility of aluminium, having road authorities, producers, material providers, designers, engineering and construction consultants, R&D, and quality assurance on board. The most critical knowledge gaps identified in this pre-project were related to global stability, fatigue, and manufacturing capability. These issues are addressed in a funded IPN project called AluBridge, supported by the Norwegian Research Council, teaming up Hydro, Dr Techn. Olav Olsen, Leirvik, Hydal, Statens Vegvesen, DNV-GL, NTNU and SINTEF. Thus, a number of experiments and scaled prototypes are tested. For instance, a number of box-girder cross-section designs are prototyped, build and tested at NTNU's wind-tunnel laboratory for verifying global stability due to wind-loads. Aluminium profiles are designed for ease of manufacturing and assembly, as well as for extracting standardized specimens for fatigue testing of welded structures exposed to traffic loads (Laser, MIG, FSW …). Furthermore, the Green Platform project AluGreen explores the use of post-consumer material in bridges, where for instance the pedestrian bridge, Hangar-bridge in Trondheim, is a case study for taking aluminium from the demolished Gyda-platform (1989-2021) and reuse in this 55 meter span all-aluminium bridge at a 95% lower CO2e than from primary and with expected 50% lower LCC. In summary, material substitution in critical road infrastructure that has an expected lifetime of 100 years is not straightforward. Many rules, regulations, actors and ingrained existing value chains causes major barriers for entering a new material to the scene. However, co-creation in terms of assembling all critical stakeholders in pre-projects, R&D projects etc – reflecting and learning within the same context and upon the same challenges may over time overcome such barriers.

Ships: The **BRIM** project started in June 2017, initiated by Arni Sigurbjarnarson the founder of North Sailing. The team behind Brim Explorer has a long tradition of providing spectacular nature experiences onboard their classic oak ships. Now the time had come to create a modern interpretation on the classic oak ships, while respecting and elevating the qualities that had made an experience on board a North Sailing ship such great success. The Catamaran is built by Maritime Partner in Aalesund and the hull construction is built in aluminum for light weight and minimal resistance in water. The Catamaran has a hybrid engine with an electrical and mechanical engine as backup. The large window section on top deck makes the catamaran excellent for touristic view and has environmental aspect to use in the fjords. The hole ship is built by Norwegian suppliers with an electrical battery package on 800kWh, it can go 8-10 knots for nearly ten hours and with use of bio-diesel engine it can increase up to 20 knots. Brim Explorer saw a huge potential in levering their experience from the whale safari expeditions in Iceland and doing the same in Norway, but with a

modern and larger vessel. The vessels they used in Iceland was mainly rebuilt and fishing boats made in oak and not optimized for tourist expeditions. The main challenge for market introduction was to keep the cost down considering it was totally new high-tech concept and timing, being ready for the whale sightseeing season, that occurs only twice a year. Aluminum was chosen due to its environmental properties and the shipyards extensive know-how in producing vessels in aluminum. The geometric/architectural design of the ship lent itself to be made in aluminum to emphasize the precision and elegant detailing of the ship. Brim explorer was a totally new design in aluminum, with optimized hull design, propulsion technology and designed for maximum comfort and visibility of the marine wildlife and scenery outside the ship. For the owners, a ship in aluminum, mostly by 75% recycled aluminium, represented a new approach, since the former ships were refurbished old ones made of oak. The way the new ship was designed in aluminum, and the high technological content of the propulsion introduced something totally new to a rather conservative market. 25th of October 2019 the first vessel "BRIM" was christened in Tromsø and number two: BARD in early 2020.

The **Urban Water Shuttle / TRAM** project was innovation projects where the objectives are to reduce urban conjunction, reduce emissions and reduce infrastructure costs. The goal is to make an all-aluminium energy efficient, zero-emission fast going passenger vessel to be used in densely populated areas located close to the sea, lakes or rivers. The first vessel is the Medstraum operated by Rogaland Fylkeskommune in Stavanger. The project was initiated by NCE Maritime CleanTech as a Pilot-E project together with the partners Wärtsilä (Bøtmlo og Stord), Servogear, Fjellstrand, Grenland Energy, CFD Marine, Hydro and NTNU. The vessel shall take 150 passengers and reach the speed of 23 knots. One sub-project was to develop and produce aluminium gearboxes (transmission).

They had tried to cast aluminium gearboxes some years ago, but faced challenges due to quality, cracks and fatigue. Thus, the traditional way in recent years has been to source large blocks of aluminium to be cut and machined to right dimensions and tolerances, causing long process time and a big pile of chips. The objective was to come up with a new lightweight design that could be casted as close to net-shape as possible. To make a first low-cost prototype it was decided to explore how the large-scale polymer 3D-printer at NTNU could provide dimensional accuracy and fine surface roughness for sand-box tooling. The full-scale prototype was rejected due to dimensional deviations of >±1.5 mm, too rough finish and difficulties of fine-machining. Also milling the negative form directly from sand-blocks was tried at a scaled prototype level, but rejected due to resource limitations in the project. The selected prototype approach was machining negatives out of plastics (Ebablock 920) although this is a quite expensive material with long lead times. Weight- and strength optimization of the gear-box was done at Aludyne in Farsund by the FEA modeling tool SutCast. Three full-scale prototypes, pre-serial production, was conducted at AluDyne by their LEAN tooling concept and low-pressure die-casting process. Time-to-market was cut by 50% and a close to net shape casting process reduced the material and energy consumption by 80%. This case is an example on how different prototyping approaches are explored and selected, and how an actual full-scale prototype in aluminium is made. To realize the concept the original consortium had to bring in Aludyne as a sub-contractor, as well as an independent casting expert.

PCS: In recent years more and more attention has been paid to introduce post-consumer material in new products. The drive for this scenario comes from the society, customers and the aluminium industry itself, where the main goal is to reduce energy consumption and overall climate footprint. Examples of innovations and impact cases from NAPIC are briefly described in the following:

- Railing systems for residential and commercial buildings developed by IDT Solution in collaboration with NTNU and Sintef Manufacturing – utilizing up to 80% PCS ratio. The challenge is to make the component as lightweight as possible in parallel to withstand safety impact criteria as well as joining and corrosion tests (2022).
- Automotive safety parts such as bumper beams, crash box systems, wheel suspension systems et by for instance by Benteler Automotive and Raufoss Technology are now subject to new material regimes where customers, car manufacturers world-wide, requires more and more PCS from

2025. These specialized and narrow alloys are sensitive and today based on primary aluminium to control the limits, but the projects AluGreen and AdaptAl conduct research into alloy composition, fatigue, weldability, corrosion and forming to make sure that the first product to Porsche in 2025 is verified by at least 11% PCS content. These criteria increase successively towards 40 and 50% towards 2030 (2022).

- Pedestrian bridges from Leirvik is designed with high PCS content, where for instance the Hangar bridge in Trondheim will be build by close to 100% PCS in 2025. This is possible due to research projects like AluBridge and AluGreen within the NAPIC domain, verifying weldability, fatigue and corrosion resistance.

Aluminium reinforces concrete: The construction industry accounts for approximately 40% of the world's climate emissions, where concrete, steel and cement are crucial negative contributors. Recently, an innovation is launched by Hydro, SINTEF and NTNU for using aluminium reinforced concrete, building with low-emission materials that can be recycled, have a longer service life, and uses less material. The research project DARE2C, started in 2017 and is based on the idea that using aluminium as reinforcement results in durable concrete structures and enables the use of more environmentally friendly binders that lower the concrete's carbon footprint considerably more than the low-carbon concretes currently available. In general aluminium cannot withstand the high pH of today's commercially available concretes, but replacing it by a high amount (>50%) of the cement in the concrete with a binder like calcined clay, and thereby reducing the pH to <10 where aluminium is stable. Thus, the Al reinforcement does not need to be covered and less concrete is needed. After five years of research a low-carbon concrete is developed featuring solid mechanical properties and aluminium compatibility. The concrete mix has not been commercialized, but from a theoretical perspective, calculations show that the new concrete can reduce CO_2 emissions by 70% compared to concrete with 100% Portland Industrial Cement (CEM I).

So far, innovations and pilots such as walkways (Gjeitbåtmuseet-2021), wall elements (High-school), quay sections (roll-on/roll-off ramp at Hydro Sunndal-2021), outdoor benches (Hareide-2019), stairs (NTNU fro Hesthagen to Gløshaugen-2023) and the private bridge (Grødøla-2023) made of aluminium-reinforced concrete are built and is subject to long-term testing and validation.

5. Sources to corroborate the impact

Aluminium reinforced concrete:

NRK: https://www.nrk.no/mr/ny-bru-i-sunndal-med-framtidas-betong-reduserer-co_-utslepp-med-80-prosent-1.16520587

Christie Opsahl: https://www.christie.no/ny-roro-kai-pa-hydro-sunndal-ferdigstilt-av-christie/

SINTEF: https://www.sintef.no/siste-nytt/2019/snart-kan-aluminium-erstatte-stal-som-armering-i-betongkonstruksjoner/

Ships:

Rogaland Fylkeskommune: https://www.rogfk.no/aktuelt/hedret-for-verdens-forste-helelektriske-hurtigbat.132190.aspx

Hydro: https://www.shapesbyhydro.com/en/manufacturing/why-aluminium-hulls-for-pleasure-boats-speak-to-performance-as-well-as-preference/

BRIM: https://brimexplorer.com/no/om-oss

Bridge:

Teknisk Ukeblad: https://www.tu.no/artikler/forsker-videre-vegvesenet-hydro-og-leirvik-vil-bygge-vedlikeholdsfrie-aluminiumsbruer/496019

Statens Vegvesen:
https://www.vegvesen.no/vegprosjekter/prosjekt/sykkelrutertrondheim/nyhetsarkiv/kan-sette-standarden-for-fremtidas-aluminiumsbruer/

PCS:

Gemini: https://gemini.no/2022/01/la-lettmetall-hjelpe-det-gronne-skiftet/

Nexans: https://www.nexans.com/en/newsroom/news/details/2023/01/nexans-and-trimet-improve-the-eco-balance-of-power-cables.html

NCEE: https://ncce.no/en/metallco-investerer-100-millioner-i-sirkulaerokonomien-pa-ora-2/
IDT Solutions: https://idt.no/aktuelt/storavtale-for-idt

MTP [3]

Institution: Norwegian University of Science and Technology
Administrative unit: Department of Mechanical and Industrial Engineering
Title of case study: Project Norway
Period when the underpinning research was undertaken: 1999-2023
Period when staff involved in the underpinning research were employed by the submitting institution: 1999-2023
Period when the impact occurred: 2000-2023

1. Summary of the impact

Project Norway is a partner-based virtual research center, owned by NTNU and with about ten research partners and fifty enterprise partners from the private and public sector. The research undertaken governed by the center is user-driven and has produced a large volume of practically-oriented research reports, many containing new processes, models, and other recommendations. These have been taken up by the enterprise partners on a large scale and caused tremendous impact on the development and execution of large and small projects across multiple sectors in Norway. This has arguably led to better projects being sanctioned, executed with fewer cost and time overruns, and with higher benefits and better sustainability.

2. Underpinning research

The Project Norway center was established in 1999 and has on average been run with direct partner funding of approximately 5 million NOK per year. This direct funding has been used as seed funding to elicit further funding to specific projects from funding sources such as the Research Council of Norway, EU, etc. On average, the total annual research budget of activities governed by the center has been about 50 million NOK. Thus, during the 25 years of operation of the center, a large number of individual research projects has been carried out. In some cases, single projects have produced specific output that has caused concrete impact, in other cases it is an accumulation of findings from many projects that have led to impact. As such, only examples of specific research output can be mentioned here:

- Research projects governed by Project Norway are by nature applied research. They are typically initiated either by public or private sector enterprise partners experiencing problems or shortcomings in their project management practices or by researchers identifying knowledge and practice gaps. The research projects are normally designed as some form of action research, where shortcomings are identified, new models/processes/tools are developed to mitigate these, and often with pilot implementations of the output from the research. After completion of the research, much effort is invested in disseminating the research outcomes, both through academic publishing in international journals and conferences as well to the center partners and the rest of the project industries, through knowledge arenas, industry associations, conferences, popular scientific reports, direct enterprise support, etc.
- The MTP department has “owned” the Project Norway center since its inception in 1999 and researchers at the department have been instrumental in initiating and managing a good share of the research projects governed by the center. Examples of underpinning research produced are new methods to identify and manage project uncertainty, processes to speed up the development and execution of projects, strategies that can be utilized by contracts owner and contractors to improve the sustainability of projects, a performance measurement system for project execution, and an improved process for project stakeholder management.
- The research projects leading to these outputs, along with many others, have been carried out during the life of the center, from 1999 and to the current date.

- Key researchers:
    - Asbjørn Rolstadås, professor and founder of Project Norway, active from 1999-around 2020
    - Bjørn Sørskot Andersen, professor, current center director of Project Norway, active from 1999 up to current date
    - Bassam Hussein, associate professor, active from 1999 up to current date
    - Nils Olsson, professor, active from his employment at MTP in 2013 up to current date (previously active when employed at SINTEF and other NTNU departments)
    - Jan Alexander Langlo, associate professor, active from his employment at MTP in 2018 up to current date (previously active when employed at SINTEF and as adjunct professor at MTP from 2011-2018)
    - Nora Johanne Klungseth, associate professor, active from her employment at MTP in 2019 up to current date
    - Haavard Haaskjold, associate professor, active from his employment at MTP in 2021 up to current date

3. References to the research

Selected key outputs, which represent a small selection of research projects that have had extensive impact on the Norwegian construction industry through take-up of the research findings:

- Author(s): Ole Jonny Klakegg, NTNU Institutt for bygg- og miljøteknikk, Vegard Knotten, NTNU Institutt for arkitektur og planlegging, Anita Moum, Sintef Byggforsk, Jardar Lohne, NTNU Institutt for bygg- og miljøteknikk, Geir Karsten Hansen, NTNU Institutt for arkitektur og planlegging og Nils Olsson, NTNU Institutt for maskinteknikk og produksjon.
- Title: Veileder for fasenormen «Neste Steg»», Et felles rammeverk for norske byggeprosesser.
- Year of publication: 2015
- Type of output and other relevant details required to identify the output (for example, DOI, journal title and issue): The output is a new stage-gate model for construction projects, documented in several reports (first version https://prosjektnorge.no/wp-content/uploads/2017/11/veileder-for-stegstandard-ver-1.2-med-logoer-201116.pdf), an Excel tool (https://prosjektnorge.no/wp-content/uploads/2017/11/neste-steg_v1.2_19november2016.xlsx), and academic paper (https://prosjektnorge.no/wp-content/uploads/2017/11/wbc16_knotten_hosseini_klakegg_next_step_a_new_systematic_approach.pdf). In May 2023, the model was made an official Norwegian Standard, Steg og leveranser i byggverkets livsløp – NS 3467, which makes it a template used by a very large number of construction projects in Norway, https://standard.no/fagomrader/ns-3420-/steg-og-leveranser-i-byggverkets-livslop--ns-3467/.
- Details to enable the panel to gain access to the output, if required (for example, a DOI or URL)

- Author(s): Key members of the project consortium, with main editors being Erling Graarud (ViaNova), Thomas Haneborg (Metier OEC), and Bjørn Sørskot Andersen (NTNU)
- Title: Samtidig prosjektering (English translation “Concurrent Engineering”)
- Year of publication: 2019
- Type of output and other relevant details required to identify the output (for example, DOI, journal title and issue): The output is a web portal, https://www.samtidigprosjektering.no/, containing a detailed step-by-step methodology that projects can adopt to implement concurrent engineering and planning in their projects. Many public sector project owner agencies use the methodology, which has saved the Norwegian state considerable time and money in the execution of large transport infrastructure projects.

- Author(s): Youcef Zidane and Bjørn Sørskot Andersen
- Title: Causes of Delay and their Cures in Major Norwegian Projects
- Year of publication: 2018
- Type of output and other relevant details required to identify the output (for example, DOI, journal title and issue): This paper (https://journalmodernpm.com/article-view/?id=285) is one of a large number of publications that were produced as part of the SpeedUp research project (https://prosjektbanken.forskningsradet.no/project/FORISS/235160). The project was funded by the Research Council of Norway, with a consortium of public and private sector enterprises and with researchers from Sintef and NTNU. The objective of the project was to empirically identify factors that cause construction projects to take longer than necessary to initiate and execute and make recommendations about how such projects can be "sped up". During the research project, many pilot projects applied the recommendations and demonstrated significant time reductions, and the methods are actively used in industry today.

4. Details of the impact

This impact case is somewhat different in that it is a permanent research center that has run a large portfolio of individual research projects during the span of 25 years. However, exactly for that reason, it is quite clear how impact has been created: Project Norway is a center established as the permanent continuation of a research project initiated by five of the biggest project owners in Norway. During the life of the center, industrial executives have made up the board of the center. Based on proposals from industrial partners from the public and private sector or research partners, an annual procedure has triggered a large portfolio of research projects. These research projects have typically produced a combination of academic papers, research reports, master and PhD theses, popular-scientific reports, specific new processes, tools, etc. Due to these projects being industry-initiated and carried out in collaboration between researchers and enterprises, it is ensured that the research outputs are relevant and possible to implement in real life. Furthermore, in many research projects, pilot implementations have been part of the research methodology, further ensuring the practical aspect of the research. After completion of the research projects, much effort has been invested in disseminating the research outputs, through mechanisms such as seminars, facilitated knowledge arenas, conferences, etc. When the center celebrated its 20 year anniversary in 2019, in preparation for the annual conference, a review was undertaken of the research project undertaken during that period. A main conclusion was that a trajectory could be seen, where research projects were initiated due to identified knowledge and practice gaps in industry, the projects involved companies operating at the leading edge to develop new methods/processes, in the years after the execution of the research, other progress-oriented enterprises took up the results, and after typically eight to twelve years, what was early on novel recommendations had become established practice in the industry at large.

The impact created has thus been changes in practice on a broad scale, in public and private sector enterprises throughout project-based industries such as construction, transportation, energy, ICT, etc. Some years ago, we calculated that the project investment portfolios of the partners in the center amounted to about 700 billion NOK, roughly 50% of the gross national product. Even minor improvements in project processes that induce saving in time or cost or lead to higher produced benefits from these projects accumulate to massive impact. Another way impact has been achieved has been the continuous transfer of new knowledge produced through Project Norway research to the continued education program in project management offered by NTNU. This program is now forty years old and has had thousands of project managers take individual courses, specialization packages, or master degrees that have been built on this research. These "students" work at various levels throughout the project-based industries in Norway, from regular project members to project directors and CEOs. This is a direct path from research to impact.

As mentioned earlier, Project Norway is a center with many academic partners, in total eight Norwegian universities and two research institutions. The level of engagement from these ten

academic partners varies, but NTNU is the key partner, both as the institution that owns and operates the center on behalf of the whole community and as the institution that supplies the research projects with the largest number of active researchers. The Department of Mechanical and Industrial Engineering has the center director and the whole Project and Quality Management Group is actively involved in the center's research.

The beneficiaries of the Project Norway research are many (see the full list of current partners at https://prosjektnorge.no/prosjekt-norge/partnere-styret-2/):

- Almost all of the state-owned infrastructure and building agencies, such as the road, rail, aviation, coastal transport, public buildings, etc. agencies
- A number of municipalities, including some of the largest cities in Norway
- Major private sector enterprises throughout the project value chain, such as architects, engineering consultants, contractors, and advisors
- Industry associations, for energy, construction, etc.
- In addition, the project owners and the large contractors engage other suppliers and thus disseminate new practices to these through construction projects

The type of impact has already been outlined; partly general inspiration from research to improve and change their practices and partly putting to use specific knowledge, methods, and tools developed through the research. Evidence of the impact can be seen in several ways: Reviewing industrial practice in project-oriented industries in Norway reveals how the actors actively use knowledge and processes developed through research. Empirical data, where the most reliable database is the Concept TrailBase with 20+ years of data about the performance of large state investment projects, shows that Norwegian projects generally perform very well, with a strong clustering of projects around the expected cost value and within the allocated budget. Furthermore, for a small country, the research community centered around Project Norway is among the largest in the field in the whole world, and Norway has earned a very favorable international reputation for strong project management performance, both in academia and industry.

Given the permanent nature of the Project Norway center, it is impossible to give dates when impact was achieved, this is a continuous achievement.

5. Sources to corroborate the impact

The most relevant sources would be representatives from the enterprise partners, past or current, possibly favoring representatives who have served on the board or held other positions in the center. Some suggestions:

- Linda Sunde Eriksen, Statsbygg, current Director of the Board of Project Norway
- Bård Atle Hovd, Aker BP
- Harald Lundqvist, Avinor
- Håvard Stensrud, Equinor
- Kjell Davik, Statens Vegvesen
- Astri Swenkerud, Statnett
- Kjersti Kvalheim Dunham, Norconsult
- Jan Henry-Hansen, OPAK
- Ari Soilammi, RIF (Consulting Engineers' Association)

[NTNU MTP] [4]

Institution: Norwegian University of Science and Technology (NTNU)
Administrative unit: Department of Mechanical and Industrial Engineering (MTP)
Title of case study: Knuckle Boom Crane Payload Motion Compensation
Period when the underpinning research was undertaken: 2015-2019
Period when staff involved in the underpinning research were employed by the submitting institution: 2015-present
Period when the impact occurred: 2019-present

1. Summary of the impact

This case study highlights the significant advancements made in payload motion compensation for knuckle boom cranes, a key focus of the SFI Offshore Mechatronics' research initiative. Conducted between 2015 and 2019, this research was a part of Work Package 2 'Motion Compensation'.

Cranes play a crucial role in both offshore and onshore industries, tasked with moving payloads accurately and safely. A severe problem with offshore cranes is the tendency to have excessive pendulum motion of the payload. The minimization of payload pendulum motion is critical to avoid hazards and disruption of crane operations. The core achievement of this project is the development of a novel algorithm at NTNU for damping unwanted payload pendulum motion. This groundbreaking technology has been successfully integrated into the commercially available Anti-Sway Rotator product of National Oilwell Varco. This integration has significantly enhanced the efficiency and safety of lifting operations, while also reducing operational costs. The technology has been adopted by industry leaders such as National Oilwell Varco and Transocean, showcasing its practical application and impact in real-world scenarios.

2. Underpinning research

Cranes play a crucial role in various operations, both onshore and offshore, where they are involved in hoisting substantial payloads. These operations carry inherent risks due to the movement of heavy loads, particularly during the landing phase. Misjudging the motion of the payload at this stage can result in equipment damage and pose a significant risk of injury to personnel at the landing site. At present, most offshore crane operations are manually controlled by an operator, lacking automated systems to mitigate the payload's sway. The introduction of automatic control systems in offshore cranes could markedly enhance the safety of these operations while also minimizing delays. By implementing automation, the precision and predictability of crane movements can be significantly improved, reducing the potential for accidents and improving operational efficiency.

Tysse et al. [1] introduced a control system featuring a Lyapunov-based damping controller, aimed at stabilizing the pendulum dynamics of a crane's payload. This specific controller was tailored to work in conjunction with a tracking controller, which manages the crane tip's position and the length of the cable. The primary objective of the Lyapunov-based controller was to stabilize the pendulum dynamics, thereby streamlining the design process for the tracking controller. This work builds on the control system presented in [4] with the addition that the crane tip also moves in the vertical direction, the cable length was controlled, and experimental validation was included.

The tracking controller employed was a nonlinear MPC (NMPC) controller. Due to the stabilization provided by the Lyapunov-based controller, the NMPC controller could operate with a reduced sampling frequency and less computational complexity. One significant advantage of this was that the NMPC controller didn't have to focus on damping the pendulum's oscillations. This simplicity allowed the NMPC problem to be executed in real-time effectively.

The design of the Lyapunov-based controller ensured exponential stability in the pendulum system when unperturbed. In practice, this means that the pendulum motion remained within controlled limits when subject to bounded perturbations. Additionally, the NMPC was developed to ensure that the actions of the tracking controller only introduced limited perturbations to the pendulum dynamics. Consequently, the crane tip and cable length were able to follow a desired trajectory while maintaining controlled pendulum motion.

The effectiveness and performance of this controller setup were not only validated through simulations but also through practical experiments using a scaled-down laboratory model of a knuckle boom crane. The experimental setup of the knuckle boom crane was presented in [2] where the authors presented an innovative experimental setup demonstrating a vision-based control system, integrating a novel methodology for real-time cable length estimation. This approach represents a significant contribution to the field of crane control technologies.

Central to this experimental setup was the deployment of a tri-camera sensor configuration affixed rigidly to the crane king, a methodology not previously utilized in crane control research. These cameras were tasked with the continuous monitoring of two spherical markers attached to the payload cable, utilizing the markers' chromatic and dimensional characteristics for precise tracking. To refine the accuracy of spatial measurements, the researchers applied the direct linear transformation algorithm, specifically adapted for a system utilizing three cameras.

The system's capacity to estimate the orientation angles and angular velocities of the payload was facilitated by an extended Kalman filter. This aspect of the research addressed a notable gap in crane control studies, where the length of the cable is often presumed to be known. Contrary to this assumption, estimation of the cable length was done with the least-squares technique with projection, based on an adaptive law.

The implementation of a linear cascade controller within the system was instrumental in damping the oscillations of the payload and in regulating the position of the crane tip. The primary output of this controller was the commanded acceleration of the crane tip, subsequently converted into a velocity signal, aligning with the conventional control input modalities for crane operations.

Underpinning these results are research on the dynamic interaction of a heavy crane and a ship in wave motion [6], which build on the dynamics model presented in [3], and was extended in [5].

The research was performed as part of Work Package 2 Motion Compensation in SFI Offshore Mechatronics. The key researchers were PhD candidates Geir Ole Tysse and Andrej Cibicik under the supervision of Professor Olav Egeland in the period 2015-2020. Associate Professor Lars Tingelstad contributed to the software implementation of the controller presented in [1]. All contributors were members of the Robotics and Automation group at the Department of Mechanical and Industrial Engineering.

The primary results of this impact case, as presented in [1], was submitted on 23 October 2019, accepted for publication in Automatica (level 2 journal) in January 2022, and published online 18 March 2022.

3. References to the research

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Details of the impact

The SFI Offshore Mechatronics project, operational from 2015 to 2023, is a prime example of how research can underpin significant advancements in the field of offshore operations, particularly in the development of advanced mechatronic systems. Coordinated by the University of Agder (UiA) and involving key university partners like NTNU, this project has substantially contributed to the evolution of autonomous, safe, and efficient operations in harsh maritime environments.

The project's objective was centered on the development of advanced mechatronic systems for offshore facilities. This was supported by a substantial grant from the Research Council of Norway and significant contributions from industrial partners, totalling 215 million NOK. Work Package 2, under the leadership of Professor Olav Egeland from NTNU, focused on motion compensation, a critical aspect of autonomous offshore operations. This package included theoretical advancements that were fundamental in evolving automated motion compensation systems. The work was divided into eight subtasks, driven by PhD and Postdoctoral researchers, and culminated in numerous publications in high-ranking academic journals.

The project involved a dynamic exchange of knowledge and expertise between academic researchers and industrial partners. An innovation manager was employed to bridge the gap between academic research and its practical application, ensuring that the research findings were effectively translated into innovative solutions. Collaboration extended beyond academia, with industrial partners actively participating in the project. National Oilwell Varco (NOV) collaborated with PhD Candidates Geir Ole Tysse and Andrej Cibicik and incorporated their payload motion compensation algorithm into the company’s development and implementation of their anti-sway rotator technology.

The SFI Offshore Mechatronics Final Report 2015-2023 includes a significant statement from Peder Sletfjerding, the department manager for Robotics and Automation at NOV, highlighting the crucial role of academic-industrial collaboration in advancing crane technology. Sletfjerding notes,

"The PhD students initially developed it, and we have since refined and adapted it to suit our cranes. It provides a more secure system and expands the use of the crane."

This statement underscores the foundational contribution of the PhD students in the initial development of the new technology. The collaborative efforts between the academic researchers and the industry experts at NOV were essential in refining and customizing this technology to meet the specific needs of NOV's crane operations. The result was not only a more secure system but also an expansion in the functional capabilities of the cranes, enhancing both safety and operational efficiency in offshore settings.

Beneficiaries of the impact include industrial partners like NOV and Transocean who have directly benefited from the implementation of this new technology. Crane operators and deck crews have experienced enhanced safety and efficiency in their operations. The broader offshore industry has gained from the advancements in technology, leading to safer, more efficient, and environmentally responsible operations.

The anti-sway rotator technology developed through this collaboration minimizes load sway and enables 360-degree rotation of loads, marking a substantial improvement over traditional methods. This technology has been particularly effective in reducing the risks associated with offshore lifting, especially in harsh weather conditions.

The impact of this research is evident in the practical application of the anti-sway rotator technology on Transocean rigs. A testimonial from Dan Haslam of Transocean in Offshore Magazine on July 18, 2022, underscore the technology's effectiveness in enhancing safety and operational efficiency: "Moving our people away from the load during lifts takes us further down the road of risk reduction. With the added benefit of more efficient deck operations, we are excited about this technology."

The significant milestones of this project were marked by the development and subsequent implementation of the anti-sway rotator technology, with a notable announcement made on July 18, 2022, regarding its adoption by Transocean in collaboration with NOV.

5. Sources to corroborate the impact

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3. https://www.offshore-mag.com/business-briefs/equipment-engineering/article/14279845/transocean-nov-partner-on-crane-antisway-rotator-technology
4. Transocean – The Crane Anti-Sway Rotator: https://www.youtube.com/watch?v=DhtXsEVTqpQ
5. https://www.linkedin.com/posts/transocean_crane-anti-sway-rotator-technology-activity-6954821155362942976-PRPP/
6. https://www.uia.no/en/news/from-research-to-product-nov-now-uses-a-new-offshore-crane-technology-created-in-collaboration-with-uia

NTNU - MTP [impact case 5]

Institution: Norwegian University of Science and Technology
Administrative unit: Department of Mechanical and Industrial Engineering
Title of case study: TrollLABS
Period when the underpinning research was undertaken: 2014 - 2024
Period when staff involved in the underpinning research were employed by the submitting institution: 2014 - 2024
Period when the impact occurred: 2015 - 2024

1. Summary of the impact (indicative maximum 100 words)

The KPN TrollLABS project (RCN project 236739) which ran from 2014 to 2018 merged lessons learned from a decade of extreme prototyping, maker space, project/problem-based teaching and design thinking into a design and engineering process and space that allows extremely rapid exploration, prototyping and testing of novel technical ideas and concepts, spanning all problem relevant disciplines such as ME, CS, material, mechatronics, control systems, signal analysis etc. It created the foundation for a new maker focused teaching approach at the departement and beyond, with daughter and sister labs at various other NTNU faculties, other global partners and at industry.

2. Underpinning research (indicative maximum 500 words)

Today´s challenging problems are almost by nature complex or wicked, and thus demand an immediate interdisciplinary approach. Hence both the team and the lab should focus on establishing a wide and solid core skill base and to explore and build early stage protypes fast. Core for technical systems is the combination of ME, mechatronics, CS plus the problem context discipline such as medicine, bridged by a design thinking-based mindset and a human centered design culture. This stands in stark contrasts to today´s organizational structure at universities. The key to fast and daring innovation is a focus onto rapidly cycling through the divergent and convergent phases of the design build test and reflect cycle. Speed is key as it allows a constant reevaluation and adaption of the problem understanding and the solution proposition. Very fast cycles of normally one or two weeks maximum, generate vast amounts of prototypes and thus learnings which in turn speeds up the development and lowers the costs. The emphasis onto experiments also lowers the perceived risk for the participants, enabling the team to take more extreme innovation pathways.

Easy access both physically and administratively to machines and equipment as well as general tools and team spaces lower the barriers to explore and test and thus drastically improve innovation level, number of prototypes, and learning speed. Besides an open culture in such a maker space, direct physical proximity and the absence of technical and administrative hurdles are key.

These insights, constantly researched and improved at TrollLABS, generated a multitude of very successful and innovative collaboration projects, technical solutions, academic publications, patents, and startups as well as 5 world records and one Paralympic Gold medal. More importantly, it created a new way of teaching, novel and unique teaching spaces and a strongly engaged and highly motivated student body that other leading universities globally aim to copy. A good indicator is the continuous invitation to joint teaching projects with Stanford University and an ongoing exchange with both Stanford University und UC Berkeley, financed by the US partners.

key researchers (in alphabetical order):

- Christer Elverum, Assoc. Prof.
- Federico Lozano, Assistant Professor II
- Håvard Vestad, researcher/lecturer
- Martin Steinert, Prof. and founder of TrollLABS
- Matt Lynch (now Assoc Prof. at NMBU)
- Sindre Eikevåg, researcher/lecturer
- Stephanie Balters (now Instructor (faculty) at Stanford University)

3. References to the research (in alphabetical order)

Gerstenberg, A., Sjöman, H., Reime, T., Abrahamsson, P. and Steinert, M.,
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Lynch, M., Kamovich, U., Longva, K.K. and Steinert, M.,
Combining technology and entrepreneurial education through design thinking: Students' reflections on the learning process.
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Technological Forecasting and Social Change, *164*, p.119689.
https://doi.org/10.1016/j.techfore.2019.06.015

Pitsis, T.S., Beckman, S.L., Steinert, M., Oviedo, L. and Maisch, B.,
Designing the future: strategy, design, and the 4th industrial revolution—an introduction to the special issue.
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https://doi.org/10.1177/0008125620907163

4. Details of the impact (indicative maximum 750 words)

In 2014 the KPN TrollLABS project provided the operational seed funding for four PhD positions in a novel research and teaching lab that is focusing onto understanding and doing skunk work like early innovation projects. The core aim, namely, to conduct better and faster new radical product /system development was tackled by 1) interdisciplinary teams from day one, 2) co-location of people and machines/processes, 3) combining Design Thinking methods and SCRUM/Agile/Lean, and 4) consciously altering through prototyping materials. After a first protptype built via containers, and based on the support from MTP a phsical space and teaching program was set up and in 2015. The core principles of this renaissance inspired research lab based on Socratean principles for students, researches and practitioners are:

- Radical *project/problem based* – real complex challenges
- Radical *interdisciplinary collaboration* – researcher from all problem relevant departments invited
- Radical *co-location of tools, machines and skills* – minimize barriers to ideate and prototype
- Radical *process coaching* - Design Thinking, cum SCRUM cum Lean
- Radically *flipped Classroom* – physical in workshop lectures and and small group coaching

This highly successful setup proved to attract many students and follow-up projects, interests from partners at other faculties and departments as well as from industry. It became a lighthouse project on how to span the boundaries of engineering, creativity & ideation, concept generation and innovation. In 2017 a first daughter lab was created by the medical faculty, TrollLABS Medical that gave the lab a better access to interact with medical personal and researchers, starting many biomedical engineering projects. Other departments copied elements and in 2018 TrollLABS became a cornerstone and WP in successful National Center of Excellence in Education application, SFU ENGAGE. Also, various companies and other organizations have taken over conceptual elements for both the maker space and the internal processes. Examples are Laerdal Medical AS, Kongsberg AS, NCE iKuben and its member companies etc. Also, a host of start-up companies have been directly effected or even grown out TrollLABS. Examples are Vitroscope, Maritime Robotics, Dignum, and the hardware incubator FAKTRY and its companies etc. So far three patents have been generated. Also internationally the project had significant impact, as it allows NTNU to collaborate with the leading maker space activities globally, such as Stanford University ME and d.school, UC Berkeley ME and Jacobs Design Center, Aalto University and its global Design Factory Network, CERN Ideasquare and many others. Overall TrollLABS has become a leading center of both conducting and researching experimental prototyping projects.
Based on the results and insights gained, the department has in 2020-2022 invested substantial infrastructure funds in creating the most advanced and inclusive maker space student infrastructure at NTNU. “Ubåten” and “Flex “were inaugurated in 2022. They serve around 500 students and assure that the focus onto skill training and experiential education is accessible for all MTP bachelor and master students.

The following gives an overview over the resulting deliverables form the initial RCN and MTP seed funding:

Research output

- 15 PhDs
- >200 publication since 2014
- KPN Projects (SBS, KM, NCESE, iKuben)
- SO funding NTNU (digital PhD program)

- BIA Projects (Novelda, Olympiatoppen)
- TTO Projects (tech demos, prod. development)
- Innovation Norge Projects (with St. Olavs)
- Industry projects (Laerdal, Alcoa, Renault, Henkel, Mobiliar, Kongsberg, KM, Maritime Robotics, … and various start ups)
- Olympiatoppen/SIAT cooperation and PARA projects
- TrollLABS MEDICAL LAB at St. Olavs/Øya
- various prices and acknowledgements

Teaching output

- Whole new track at NTNU
- ca. 1200 7th semester students
- ca. 280 8th semester students
- ca. 80 9th semester students
- ca. 60 master projects finished, 10 running
- Externally some 400 students and 2000 executives taught
- Exec. Master coordinated by DT Bergen
- NTNU nomination for NOKUT Utdanningspris
- NTNU/IVT innovative utdanning funding
- CERN CBI and Stanford ME310 teams
- SFU Engage
- … engaging school children through Trondheim Makers

Innovation output

- FORNY grants (DIGNUM AS, Yatek Multidir. Treadmill for VR/AR Navigation in Healthcare)
- TTO Discovery grants (Cellflow, prostate cutter)
- NTNU/IV Innovation grant
- Various TTO and Innovation Norge, Helse Mid-Norge etc. early stage grants
- 1-2 DOFIs per year (Cellflow, AUVinspect, DentalSound, REBOA, Prostate Cutter, force measurement ski pole sensor)
- 3 patents:
    - Cell Culture device (with vitroscope AS)
    - Ultrasound phantom (with Lærdal Medical AS)
    - Dimensionally stable Amorphous carbon structures
- 2 patents pending
- Participated/helped multiple Kickstarter Projects
- One company founded and active, more in pipeline

5. Sources to corroborate the impact (in alphabetical order)

1. Arne Rinnan, Executive Vice President Strategy & Technology Kongsberg Discovery AS
   https://www.kongsberg.com/discovery/about-us/who-we-are/management
2. Birgit Skarstein, Paralympic Athlete
   https://www.linkedin.com/in/birgitskarstein
   article: https://www.tu.no/artikler/over-100-prototyper-er-testet-fra-gaffatape-og-treverk-til-gullhap/512859
3. Carlo Kriesi, CEO Vitroscope AS
   https://www.vitroscope.no
   https://www.linkedin.com/in/ckriesi
4. Kalevi Ekman, Aalto University

https://designfactory.aalto.fi
https://research.aalto.fi/en/persons/kalevi-ekman

5. Konrad Lillevevang, CEO NCE iKuben
   https://ikuben.no
   https://www.linkedin.com/in/konrad-lillevevang-937a2a3
   article: https://ikuben.no/aktuelt-artikler/tidlig-fase-prototyping-med-trolllabs-i-industri-40-laben
6. Kosa Goucher-Lambert, Ass. Professor, UC Berkeley
   https://me.berkeley.edu/people/kosa-goucher-lambert
7. Magnus Ove, CTO Laerdal Medical AS
   https://laerdal.com
   https://www.linkedin.com/in/magnus-ove-ba83381b2
8. Mark Cutkosky, Prof., Stanford University
   https://profiles.stanford.edu/mark-cutkosky?releaseVersion=10.6.0
9. Markus Nordberg, Head of Resources Development at CERN
   https://ideasquare.cern
   https://www.linkedin.com/in/markusnordberg
10. Sissel Granstrøm, FAKTRY, https://www.faktry.com
    article: https://www.universitetsavisa.no/campus/faktry-vil-bli-et-felles-verksted-for-grndere/147674

Institution: Norwegian University of Science and Technology (NTNU)
Administrative unit: Department of Computer Science (IDI)
Title of case study: FINN
Period when the underpinning research was undertaken: 2012-present
Period when staff involved in the underpinning research were employed by the submitting institution: 2012-present
Period when the impact occurred: 2017-present

1. Summary of the impact

FINN was the first Field Programmable Gate Array (FPGA) accelerator for binarized convolutional neural networks, which is an important **Artificial Intelligence (AI)** workload, and **enables highly energy-efficient neural network inference**. While ubiquitously important, energy-efficient inference is particularly compelling in industrial applications due to stringent size, weight, power, and cost constraints. FINN was designed by IDI's **Computer Architecture Lab (CAL)** in collaboration with Xilinx, a global leader in FPGA technology at the time. Xilinx was later acquired by AMD, a global leader in heterogeneous and high-performance computing, and **FINN is now a key product in AMD's portfolio** (as exemplified by the customer endorsement in Section 4).

2. Underpinning research

FINN is a direct result of the strategy of IDI's Computer Architecture Lab (CAL) which is to work on fundamental and important research problems within computer architecture and publish our results at the highest international level to maximize visibility. With FINN, it was our publication at the top-tier FPL conference in 2015 that made Xilinx/AMD want to collaborate with us, and it was our research up to that point that made it possible for us to fully capitalize on this opportunity.

We will now summarize the key events in the story of FINN (and we will get back to the details in Section 4):

2012 Associate professor Jahre at CAL is awarded a PhD position to instigate research within the Energy Efficient Computer Systems (EECS) faculty-level research initiative of which he was the key founding partner. Jahre also coordinated EECS until 2016.

2012 Jahre recruits **Umuroglu** to the PhD position, and they start designing FPGA-based accelerators for sparse linear algebra applications. This activity yielded several publications (see Section 3) and was where we built the expertise we later leveraged when designing FINN.

2015 Umuroglu presents our work on accelerating breadth-first search at the top-tier conference FPL and catches the attention of **Blott**, the head of a research group at **Xilinx Research Labs**. Blott proposes to collaborate and offers Umuroglu an internship that he can do while working on his PhD at CAL.

2016 Courbariaux et al. demonstrates that convolutional neural networks with binary weights and activations can retain high accuracy. We immediately realize the potential for next-level efficiency on FPGAs due to their extreme bit-level parallelism, leverage this observation to design FINN, and submit a paper describing FINN to the top-tier FPGA'17 conference.

2017 Umuroglu presents FINN at FPGA'17. **FINN is the first binarized convolutional neural network accelerator and provides the highest image classification rates to date.**

2018 Umuroglu obtains his PhD from NTNU and joins Xilinx as a full-time researcher. The collaboration between Xilinx and CAL continues and is expanded to include associate professor Själander and his students. Xilinx devotes significant resources to bringing FINN to market.

2020 AMD announces its acquisition of Xilinx. The company continues to support FINN and the collaboration with CAL continues.

2022 AMD completes its acquisition of Xilinx. The company continues to support FINN and the collaboration with CAL continues.

2024 AMD announces the first public customer testimonial for FINN. The testimonial is provided by SICK, a ~12,000-employee global manufacturer of industrial sensors and sensor solutions. By January 2024, the **FINN paper has been cited 1,146 times** according to Google Scholar.

3. References to the research

The key publication underpinning FINN is our publication at the top-tier conference FPGA in 2017 (authors affiliated with IDI are shown in bold):

P1 **Yaman Umuroglu**, Nicholas J. Fraser, Giulio Gambardella, Michaela Blott, Philip Leong, **Magnus Jahre**, and Kees Vissers. "FINN: A framework for fast, scalable binarized neural network inference". In: *Proceedings of the International Symposium on Field-Programmable Gate Arrays (FPGA)*. 2017, pp. 65–74. DOI: 10.1145/3020078.3021744

In addition, FINN leverages the insights from our earlier research on designing FPGA accelerators for sparse linear algebra, which is covered by the following publications (again with IDI authors in bold):

F1 **Yaman Umuroglu** and **Magnus Jahre**. "An energy efficient column-major backend for FPGA SpMV accelerators". In: *Proceedings of the International Conference on Computer Design (ICCD)*. 2014, pp. 432–439. DOI: 10.1109/ICCD.2014.6974716

F2 **Yaman Umuroglu**, **Donn Morrison**, and **Magnus Jahre**. "Hybrid breadth-first search on a single-chip FPGA-CPU heterogeneous platform". In: *Proceedings of the International Conference on Field Programmable Logic and Applications (FPL)*. 2015, pp. 1–8. DOI: 10.1109/FPL.2015.7293939

F3 **Yaman Umuroglu** and **Magnus Jahre**. "A vector caching scheme for streaming FPGA SpMV accelerators". In: *Applied Reconfigurable Computing*. 2015, pp. 15–26. DOI: 10.1007/978-3-319-16214-0_2

F4 **Yaman Umuroglu** and **Magnus Jahre**. "Random access schemes for efficient FPGA SpMV acceleration". In: *Microprocessors and Microsystems* 47 (2016), pp. 321–332. DOI: 10.1016/j.micpro.2016.02.015

A more extensive summary of this line of research can be found in Umuroglu's PhD thesis.

4. Details of the impact

The Computer Architecture Lab (CAL) at IDI started focusing on specialization in 2012 in response to Esmaeilzadeh et al.'s seminal Dark Silicon paper at ISCA'11. Dark Silicon occurs when the amount of power that can be provided to a processor chip is insufficient to switch all transistors. Only a subset of the transistors can thus be used concurrently and the remaining transistors are "dark". These unused transistors can however be used to create specialized compute units, called **accelerators**, that are extremely energy efficient for a class of workloads and powered off when the system is not executing that particular workload.

CAL was the key founding partner of the IE faculty's Energy Efficient Computer Systems (EECS) strategic research initiative, and IE allocated two internally-funded PhD students to EECS out of which one was allocated to **Jahre** at CAL. Jahre wanted to investigate the potential for leveraging specialization to the Berkeley Dwarfs. The Berkely Dwarfs capture 13 key computational patterns within important classes of parallel computations, and the idea of the PhD project was to design accelerators for selected dwarfs. The goal was to balance specificity and generality which is necessary because dark transistors are a finite resource.

Jahre recruited **Umuroglu** for the PhD position. Umuroglu had just graduated from IE's highly competitive European Master in Embedded Computing Systems (EMECS) and joined the PhD program in 2012. We decided to focus on investigating accelerator architectures on Field Programmable Gate Arrays (FPGAs) for the **sparse linear algebra** dwarf. This problem is challenging because data-dependent indirect memory accesses are prevalent in these workloads. It is also an important problem because (i) general-purpose architectures generally perform poorly on these kernels, and (ii) sparse data structures are common in important application domains (e.g., engineering, data analytics, and graph processing). The key result of this line of work was our paper at the top-tier conference FPL in 2015 (paper F2 in Section 3). The self-evaluation of IDI's CAL research group presents the top-tier venues of computer architecture in more detail; conferences are generally (much) more prestigious and competitive than journals in this field.

FPL'15 took place in September 2015, and our paper caught the attention of **Blott** who at the time ran a research group at **Xilinx Research Labs** in Ireland. In 2015, Xilinx and Altera were the leading manufacturers of FPGAs in the world. Blott wanted to collaborate with us and proposed to operationalize the collaboration through Umuroglu taking an internship at her group in Xilinx as part of his PhD. Discussions continued during the rest of 2015, and Umuroglu started his internship early in 2016. At the same time, Courbariaux et al. demonstrated that the precision of weights and activations in **Convolution Neural Networks (CNN)** could be reduced from 32-bit floating point numbers to single bits while only incurring a modest reduction in accuracy. We immediately realized that this result created the potential for extremely efficient CNN inference on FPGAs because the main strength of an FPGA is its massive bit-level computational parallelism.

Umuroglu took the lead on developing a prototype, and he was ideally positioned to exploit this opportunity as it essentially required expanding his PhD project to cover the **dense linear algebra** dwarf in addition to the sparse linear algebra dwarf he had focused on until this point. For example, he could reuse several high-performance accelerator components that he had already designed (e.g., fpga-tidbits). He was therefore, with support from other interns at Xilinx, able to create and evaluate a binarized CNN accelerator prototype in record time. We then wrote a paper about the accelerator, which we named **FINN** after a hero in Irish mythology, and submitted it to the top-tier FPGA conference in the autumn of 2016.

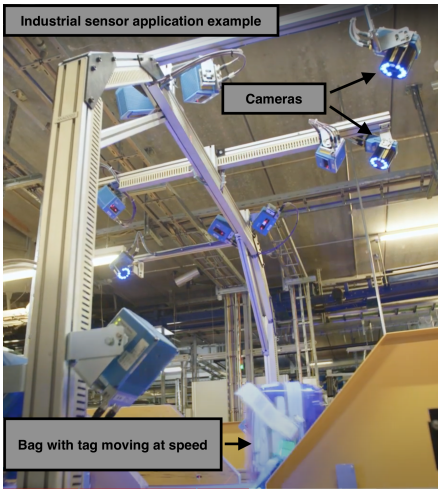
The FINN paper was accepted upon first submission and was presented at FPGA'17 in February 2017. It was **the first paper to demonstrate the significant performance and energy-efficiency benefits of performing binarized CNN inference on FPGAs.** More specifically, we demonstrated 12.3 million (21,906) image classifications per second for MNIST (CIFAR-10/SVHN) on a ZC706 platform that consumes less than 25 W. To the best of our knowledge, these were the fastest classification results for those benchmarks at that time. FINN thereby opened the field of extreme quantization in FPGA accelerators for AI and has had a **tremendous academic impact**. For example, it had accumulated **1,146 citations** according to Google Scholar by January 2024, and it is the most cited paper at the top-tier FPGA conference since 2017.

Even if AI had not yet become mainstream in 2017, it was clear that AI would be an important workload going forward. FINN therefore had significant commercial potential. **Xilinx hence threw considerable resources behind the project** and hired Umuroglu after he obtained his PhD and graduated from CAL in 2018. Xilinx was later acquired by AMD which is a global leader in heterogeneous and high-performance computing. Support for the FINN project however remained high, a testament to the quality of the contribution. Bringing fundamental computer architecture contributions to the market is time-consuming as modern computer systems are extremely complex and performance-sensitive. Moreover, the requirements of customer confidentiality mean that many use cases cannot be discussed publicly.

AMD has however recently released the following **testimonial** from SICK:

"The FINN toolset is showing huge potential using it in upcoming SICK products. It is easy to use and with an extraordinary performance and very promising results. In the future, flexible implementations of ML in our products with FINN can be a great advantage and even replace static architectures as they are currently used. Thanks to the FINN team for the great cooperation."

SICK is a global manufacturer of sensors and sensor solutions for industrial automation, has ~**12,000 employees** worldwide, and had a revenue of **2.2 billion euros** in 2022. Applying sensors in an industrial context is typically subject to severe size, weight, power, and cost constraints, and the high energy efficiency enabled by FINN is hence compelling. One example is this video which illustrates how SICK's sensors are used in an airport's baggage handling system. We obtained the image below from the video and annotated it to show the key components of the system. In such systems, AI inference is typically performed within the camera module. The reason is that it is infeasible both in terms of bandwidth and latency to transfer raw images to a server because it would require installing high-bandwidth wired connections throughout the airport. In contrast, FINN can enable reading bag tags within the camera with much higher efficiency than conventional approaches, and the system thus only has to transfer short strings (e.g., the three-letter destination airport code and the bar code). Higher efficiency can for example be leveraged to improve detection accuracy or to attain the same accuracy with a smaller and cheaper device.



The collaboration between CAL and AMD has continued in parallel with AMD seeking to bring the technology to market. Notable examples are BISMO, a collaboration between **Själander** and **Rasnayake** at CAL and Umuroglu at AMD which enables trading AI inference accuracy against performance in FPGA-based accelerators by tuning precision to application needs (paper E4 in Section 5). BISMO appeared in the top-tier FPL conference in 2018 and is the third most cited paper at FPL since 2018. More recently, we proposed BISDU which offers to bring the benefits of extreme quantization to general-purpose embedded processors (paper E6 in Section 5). AMD has also awarded a 50,000 euro gift to Själander and Jahre which will enable us to strengthen and expand the collaboration in the near future.

5. Sources to corroborate the impact

The key publication underpinning FINN is our publication at the top-tier conference FPGA in 2017 (authors affiliated with IDI are shown in bold):

P1 **Yaman Umuroglu**, Nicholas J. Fraser, Giulio Gambardella, Michaela Blott, Philip Leong, **Magnus Jahre**, and Kees Vissers. "FINN: A framework for fast, scalable binarized neural network inference". In: *Proceedings of the International Symposium on Field-Programmable Gate Arrays (FPGA)*. 2017, pp. 65–74. DOI: 10.1145/3020078.3021744 **(1,146 citations)**

Our work with FINN has directly led to several high-impact publications in high-end venues such as FPL and ACM TRETS, from AMD/Xilinx, IDI's CAL research group, and as a collaboration between both:

E1 Nicholas J Fraser, Yaman Umuroglu, Giulio Gambardella, Michaela Blott, Philip Leong, Magnus Jahre, and Kees Vissers. "Scaling binarized neural networks on reconfigurable logic". In: *Proceedings of the 8th Workshop on Parallel Programming and Run-Time Management Techniques for Many-core Architectures and the 6th Workshop Design Tools and Architectures for Multicore Embedded Computing Platforms*. 2017, pp. 25–30. DOI: 10.1145/3029580.3029586 **(72 citations)**

E2 Michaela Blott, Thomas B. Preußer, Nicholas J. Fraser, Giulio Gambardella, Kenneth O'Brien, Yaman Umuroglu, Miriam Leeser, and Kees Vissers. "FINN-R: An end-to-end deep-learning framework for fast exploration of quantized neural networks". In: *ACM Transactions Reconfigurable Technology and Systems* 11.3 (2018). DOI: 10.1145/3242897 **(363 citations)**

E3 Vladimir Rybalkin, Alessandro Pappalardo, Muhammad Mohsin Ghaffar, Giulio Gambardella, Norbert Wehn, and Michaela Blott. "FINN-L: Library extensions and design trade-off analysis for variable precision LSTM networks on FPGAs". In: *Proceedings of the International Conference on Field Programmable Logic and Applications (FPL)*. 2018, pp. 89–97. DOI: 10.1109/FPL.2018.00024 **(85 citations)**

E4 Yaman Umuroglu, Lahiru Rasnayake, and Magnus Själander. "BISMO: A scalable bit-serial matrix multiplication overlay for reconfigurable computing". In: *Proceedings of the International Conference on Field Programmable Logic and Applications (FPL)*. 2018, pp. 307–317. DOI: 10.1109/FPL.2018.00059 **(109 citations)**

E5 Yaman Umuroglu, Yash Akhauri, Nicholas James Fraser, and Michaela Blott. "LogicNets: Co-designed neural networks and circuits for extreme-throughput applications". In: *Proceedings of the International Conference on Field-Programmable Logic and Applications (FPL)*. 2020, pp. 291–297. DOI: 10.1109/FPL50879.2020.00055 **(78 citations)**

E6 David Metz, Vineet Kumar, and Magnus Själander. "BISDU: A bit-serial dot-product unit for microcontrollers". In: *ACM Transactions on Embedded Computing Systems* 22.5 (2023), pp. 1–22. DOI: 10.1145/3608447 **(444 downloads)**

We retrieved the number of citations from Google Scholar in January 2024. The number of full-text downloads was retrieved from the publisher's website.

Institution: Norwegian University of Science and Technology (NTNU)
Administrative unit: Department of Computer Science (IDI)
Title of case study: NOKIOS
Period when the underpinning research was undertaken: 2006-2023
Period when staff involved in the underpinning research were employed by the submitting institution: 2006-2023
Period when the impact occurred: 2007-2023

1. **Summary of the impact** (indicative maximum 100 words)

NOKIOS is an annual conference on eGovernment initiated by the Norwegian University of Science and Technology (NTNU) in 2006. It was started by Professor John Krogstie and collaborators. Krogstie has since been the leader of the program committee. The conference is now organized by NTNU in cooperation with a total of 25 vendors and governmental and local agencies and universities.

2. **Underpinning research** (indicative maximum 500 words)

The aim of the conference is to create a meeting place for a broad range of employees and politicians, researchers, vendors and other stakeholders in the public sector where they can get significant news about digital trends that can help them with their work. The conference features presentations, lectures and news from researchers and vendors, as is recognized as the leading eGovernment conference in Norway.

The target groups for the event are decision makers from the Norwegian public sector, politicians, managers, project leaders, vendors, IT professionals, researchers and other stakeholders working in the public sector.

Although it is a professional and not a scientific event, it provides a dissemination arena for in particular research in the eGovernment area, both from the our group, from other parts of IDI and NTNU and form other Norwegian eGovernment researchers . Examples of own research disseminated here is found below.

3. References to the research (indicative maximum of six references)

The list includes examples of research that has been presented at the conference, although presented also in scientific conference. Lately given the central role of John Krogstie in the arrangements, less of own research has been presented directly

Process models representing knowledge for action: a revised quality framework
J Krogstie, G Sindre, H Jørgensen - European Journal of Information Systems, 2006

User involvement in e-Government development projects
A Følstad, HD Jørgensen, J Krogstie - Proceedings of the third Nordic conference on Human …, 2004

What is the value of eGovernment–and how can we actually realize it?
L Skiftenes Flak, W Dertz, A Jansen, J Krogstie… - Transforming Government: People, Process and Policy, 2009

Navigating MazeMap: indoor human mobility, spatio-logical ties and future potential
G Biczok, SD Martínez, T Jelle, J Krogstie - 2014 IEEE International Conference on Pervasive …, 2014

The entanglement of enterprise architecture and IT-governance: The cases of Norway and the Netherlands
G Aagesen, AF van Veenstra, M Janssen, J Krogstie - 2011 44th Hawaii International Conference on System …, 2011

Accessibility of Norwegian municipalities websites: a qualitative system dynamics approach
AA Abdelgawad, MH Snaprud, J Krogstie - Proceedings of the 28th International Conference of the …, 2010

4. Details of the impact (indicative maximum 750 words)

The 17. annual conference was arranged in Trondheim on 24 – 26 October 2023 with around 1000 participants. Starting at 250 participants in 2007, the number has gradually increased until the comment level which has reached the capacity of the conference venue

As a meeting place it has been the starting place for a number of collaborative initiatives including enterprise architecture networks in public sector, common testdata, and common services for municipalities.

5. Sources to corroborate the impact (indicative maximum of ten references)

Benefits management and Information Technology work distribution
K Kjetil Holgeid, J Krogstie, P Mikalef, EE Saur… - 2023

Collaborating across Industry and Academia to support the Development of Sustainable ICT: The GoForIT initiative
J Krogstie, S Sommerfeldt, AL Riise, L Berge… - 2023

Differences in Information Systems Development and Evolution Practice between the Local and Governmental Public Sector
J Krogstie, AF Strømsnes - Norsk IKT-konferanse for forskning og utdanning, 2022

Krogstie, John. (2008i). Mobil helsemonitorering som eksempel på velferdsteknologi *NOKIOS*. Trondheim, Norway.

Krogstie, John. (2009f). Prosessorienterte løsninger på tvers av offentlige virksomheter *NOKIOS 2009*. Trondheim, Norway.

Krogstie, John. (2010f). Software, hardware, elsewhere or vaporware ? Offentlige IKT-tjenester i skyen. NOKIOS 2010, Trondheim Norway.

Gulliksen, Inga Viktoria Ågesdatter, Hegle, Marit, & Krogstie, John. (2007). *Innføring av elektronisk handel i offentlig sektor: Erfaringer fra Sør-Trøndelag Fylkeskommune*. Paper presented at the NOKOBIT 2007

NOKIOS web page: Hjem - NOKIOS

Institution: IDI
Administrative unit: SE-LT
Title of case study: Kahoot!
Period when the underpinning research was undertaken: 2006 - 2021
Period when staff involved in the underpinning research were employed by the submitting institution: 2006-2021
Period when the impact occurred: 2014-2023

1. Summary of the impact

Kahoot! is a game-based learning platform that aims to empower everyone, including children, students, and employees, to unlock their full learning potential. The technology is based on research conducted by Kahoot! co-founder Morten Versvik and Professor Alf Inge Wang. The work started from a game concept developed by Wang and then further developed in the context of Versvik's Master's degree at NTNU. Kahoot! utilizes state of the art game technology, and, motivational and social theories of learning. Kahoot! has hosted over 9 billion participants in hundreds of millions of learning sessions since it is launched in 2013.

2. Underpinning research

The game concept used in Kahoot! started out as an idea of Professor Alf Inge Wang in 2006. In collaboration with master students, multiple prototypes were developed and tested in experiments. The idea was to transform the classroom into a gameshow, where the teacher acted as the game show host, and the students were contenders, using their own mobile devices. The initial prototype was named Lecture Quiz. From 2006 to 2011, four versions of Lecture Quiz were developed at NTNU, mainly improving usability – making it easier to create quizzes, and technical improvement using newer technology for implementation (hardware and software).

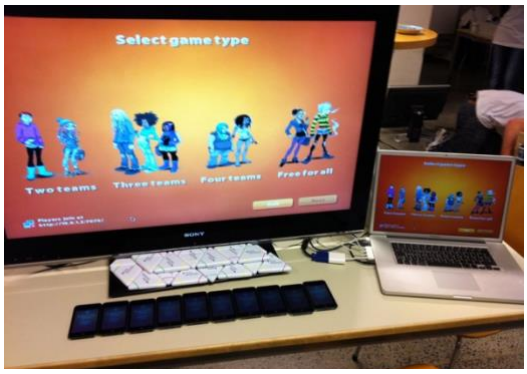


Figure 1. Evaluation of a Lecture Quiz! prototype at NTNU.

Kahoot! was founded in 2012 (launched 2013) by IDI's master students Morten Versvik, Johan Brand, and Jamie Brooker, together with Professor Alf Inge Wang, and were later joined by entrepreneur Åsmund Furuseth.

Since Kahoot! was launched and funded by the Research Council of Norway, the research experiments intensified. Lead by Prof. Wang a series of studies were conducted related to the effects of using the game-based learning platform in classrooms. For instance, a quasi-experiment conducted at NTNU with 252 students participating investigated the wear-out effect of Kahoot!, by comparing students' perception of the system after playing once, vs. playing frequently over five months (Wang, 2015). The results indicated that Kahoot! managed to boost students' engagement, motivation, concentration, and learning after using it repeatedly for five months. The core factor to keep students' attention after heavy repeated usage was found to be the competitive nature of Kahoot!.

In a follow up study, Wang et al., (2016) investigate how Kahoot! performs compared to other tools and platforms. In a quasi-experiment with 384 students at the NTNU, Kahoot! was compared to

using a paper quiz and a simple polling system. The results show statistically significant improvement in motivation, engagement, enjoyment, and concentration for the gamified approach (Kahoot!) compared to the two others.

In another quasi-experiment (Wang & Lieberoth, 2016) where 593 students participated, the authors investigated how the use of points and audio in Kahoot! affects concentration, engagement, enjoyment, learning, motivation, and classroom dynamics. The results reveal that there are some significant differences whether audio and points are used in the areas of concentration, engagement, enjoyment, and motivation. The worst result was for the case where both audio and points were turned off. The most surprising finding was how classroom dynamics was positively affected by the use of audio.

During the last years, Prof. Wang together with his PhD student (Tahir) they published a literature review containing 93 studies on the effect of using Kahoot! (Wang & Tahir, 2020). This paper was published in the leading journal in the area of learning technologies (Computers & Education) and has been the most cited paper of the journal (over 800 citations after 3 years). This is the first literature review that investigates most published studies (experiments, case studies, surveys, etc.) on how using Kahoot! affects learning in the classroom. The main conclusion is that Kahoot! has a positive effect on learning performance, classroom dynamics, attitudes, and anxiety.

3. References to the research

Our work with Kahoot! has directly led to several high-impact publications in top-tier venues such as the Computers and Education (the premier journal in the field of learning technologies):

Wang, A.I. (2015). The wear out effect of a game-based student response system". Computers & Education. 82: 217–227. https://doi.org/10.1016/j.compedu.2014.11.004 **(810 citations)**

Wang, A. I., & Tahir, R. (2020). The effect of using Kahoot! for learning–A literature review. Computers & Education, 149, 103818. https://doi.org/10.1016/j.compedu.2020.103818 **(890 citations)**

Wang, A. I., Zhu, M., & Sætre, R. (2016). The effect of digitizing and gamifying quizzing in classrooms. Proceedings of the European conference on games-based learning. https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/2426374 **(140 citations)**

Wang, A. I., & Lieberoth, A. (2016). The effect of points and audio on concentration, engagement, enjoyment, learning, motivation, and classroom dynamics using Kahoot. In European conference on games based learning (Vol. 20, pp. 738-746). https://www.proquest.com/docview/1859715026?pq-origsite=gscholar&fromopenview=true **(408 citations)**

Nuci, K. P., **Tahir, R., Wang, A. I.,** & Imran, A. S. (2021). Game-based digital quiz as a tool for improving students' engagement and learning in online lectures. *IEEE Access*, *9*, 91220-91234. https://ieeexplore.ieee.org/abstract/document/9452076 **(32 citations)**

In total there are more than 2250 citations (per Jan. 2024)

Besides high-impact publications in top-tier venues, prof. Wang has also been invited to give keynoted in prestigious game and learning technology conferences, such as:

- International Conference on Entertainment Computing (IFIP-ICEC 2015)
- European Conference on Games Based Learning (ECGBL 2015)
- ACM conference on Interaction Design and Children (IDC 2018)
- Norwegian Conference on ICT (NIKT 2019)

- Serious Games Society Conference (GALA 2023)

4. Details of the impact

Based on recent data (see: https://kahoot.com/company/), Kahoot! has hosted over 9 billion participants in hundreds of millions of learning sessions since its launch in 2013. It has been played in all countries in the world with more than 100M Kahoots!. Kahoot! is used in many institutions of higher education around the world, including 97% of the global top 500 universities. Also, half of US teachers and students have hosted or played a Kahoot! in the last year. 97% of Fortune 500 companies are using Kahoot! for training, presentations, onboarding, events and more. Kahoot! offers a free version, and also has 1.37M paid subscribers.

Figure 2. Kahoot! used in a US school (half US teachers used Kahoot! during the last year).

In 2017, Kahoot! had raised $26.5 million in funding from Northzone, Creandum and Microsoft Ventures. On October 11, 2018, Kahoot! was valued at $300 million. As of 11 June 2020, Kahoot! was valued at $1.5 billion and raised further capital from Northzone. In March 2021, the company went public on the Oslo stock exchange.

Today, Kahoot! is a company with an international team of more than 500 employees located at some of the most exciting tech hubs in the world. Kahoot! is also a big international brand and was in January 2023 ranked #3 coolest brand among European Millenials and Gen Z'ers according to YPulse's brand data tracker (above brands like Apple, Coke, TikTok and Instagram). Kahoot! has also generated many thousand media coverages nationally and internationally. Further, Kahoot! has resulted in many prices, including Teknologibragden 2014, Innovasjonsprisen Innovator 14, Digital Service that Changes the World 2014, Noodle Best Online Educational Tool 2015, 2015 EDTECH 20 Winners, Oslo Innovation Award 2016, the Europas Award – "Hottest Education Startup 2017", Product or Service Edtech award 2018, and the 2023 Merit Awards for Technology in the category education.

5. Sources to corroborate the impact

Most of the information behind the creation of Kahoot! can be found in Kahoot!'s about us section and Wikipedia page.

Moreover, Kahoot!'s story has also featured in the news, below are some examples:

- The New York Times: https://www.nytimes.com/2016/04/17/technology/kahoot-app-brings-urgency-of-a-quiz-show-to-the-classroom.html
- CNBC: https://www.cnbc.com/2021/11/02/kahoot-how-a-student-professor-duo-launched-a-5point7-billion-tech-idea.html
- The PC Magazine: https://uk.pcmag.com/education-reference/128455/the-best-online-learning-services-for-2020

Institution: NTNU
Administrative unit: IDI
Title of case study: The Norwegian Open AI Lab
Period when the underpinning research was undertaken: 2016
Period when staff involved in the underpinning research were employed by the submitting institution: 2016
Period when the impact occurred: 2017-

1. **Summary of the impact** (indicative maximum 100 words)
   Outreach, industry collaboration, education, research education.
   The Norwegian Open AI Lab is a collaboration and research initiative with partners in academi and industry. The underpinning research is all AI activities at IDI and partner departments at NTNU. The impact case is a description of the success of the The Norwegian Open AI Lab

Norwegian Open AI Lab (NAIL)

Leader: Heri Ramampiaro
Departments participating: IDI, ITK, IES, IIK, IIR, IMF, IØT

Goal and vision for the area

Artificial intelligence (AI) represents vast opportunities for us as individuals and for society at large. AI can lead to new, more effective business models and to effective, user-centric services in both private and public sector. It is on this background that AI is considered a strategic research area at the IE faculty at NTNU.

NAIL's ambition is to be the number one AI hub for cooperation between Norwegian universities, research institutes, private, and public sector within *ethical*, *sustainable,* and *trustworthy* AI. NAIL focuses on basic research topics with broad relevance, applied research and research driven innovation.

Main results (2022-2023)

This year NAIL had a total of 17 *partnerships*, an increase of 5 new partners since last year. Out of the partners 3 were from public sector, and 4 were academic research partners. New partnerships were established with Kartverket, Videocation, Akvaplan-niva, and Nordea. We also signed on NExTdigital in Ålesund that will be a key partner with regards to expanding our contact in the region, together with the now established node at NTNU campus Ålesund. We have also had meetings with several other companies, to discuss possible future collaborations.

In 2023, staff affiliated with NAIL were involved in 48 ongoing *research projects*, which marks an increase of net 13 new projects compared to 2022. New projects starting this year included the NTNU Health project *AI-MENT* (Machine learning to tailor treatments in mental health), the Horizon Europe project *TrustLLM* (Democratize Trustworthy and Efficient Large Language Model Technology for Europe), and the NFR project *ENACT* (Ethical risks assessmeNt of Artificial intelligenCe in pracTice), to mention a few. Our associated research team also had some new projects granted in 2023, that will

start in 2023. Among them were the NFR project *cAIge* (AI application for salmon health monitoring). We continue to work with already established SFIs as well as other AI actors, for example with regards to the Norwegian Artificial Intelligence Cloud (NAIC), which involves several other universities.

NAIL contributes to the AI *education* through several activities. The Nordic Probabilistic AI School was organized for the fourth time in 2023, with almost 700 applicants from all over the world, for the 160 seats available. NAIL also contributes to the activities of two student organizations, Cogito NTNU and BRAIN NTNU, to strengthen the AI students learning and social environment. Furthermore, to educate the Norwegian general public, NAIL – with Professor Helge Langseth as subject expert – has made available the Norwegian version of the massive open online course, Elements of AI – now with new chapters regarding generative AI and chatbots.

Other key contributions towards education have been co-organized with SFI NorwAI. Yearly we host an event where businesses and organizations can pitch ideas for MSc thesis topics. In our 2023 event, over 30 possible master thesis topics were presented. NorwAI and NAIL also collaborated on the pilot FEMAIS, the mentorship program for female students in artificial intelligence. The pilot was successful, and funding was sought from the Rector's funding for gender equality and diversity to continue the program. The funding was not granted, and the program is currently on hold. Furthermore, SFI NorwAI and NAIL host regular seminars, to *disseminate* AI knowledge and research. In 2023, speakers held talks on themes such as machine learning and big data, AI privacy, and news summarization.

In addition to these collaborations, SFI NorwAI also organizes research and innovation activities in accordance with their work plan. Two important events were firstly, the presentations about the NorwAI efforts on a Norwegian Large Language Model during Arendalsuka, and secondly their third annual *NorwAI Innovate conference* that was held on October 31st and November 1st 2023, with approximately 180 attendees from industry and academia. The NorwAI researchers are also partners in the Horizon Europe project *TrustLLM*, which is aimed at Large Language Models for Germanic languages.

In 2023 NAIL had AI *dissemination* as a main focus. In order to deliver on the university's societal responsibility, NAIL associated researchers contributed to multiple local, national and international conferences, news articles, podcasts and radio-shows, and panel debates. At the height of the activity, our researchers participated in dissemination events several times every week. Together with partner Videocation we launched *Ukens Aiki,* where Associate professor Inga Strümke gave short intros to AI technologies and news. Strümke has been the leading contributor to NAIL and NTNUs AI dissemination, and at the end of the year she was awarded the RCN prize "Communicator of the year". Inga also won a Brage prize in 2023 for her best-selling book: *Maskiner som Tenker*.

NAIL also contributed to internal NTNU events discussing various aspects of AI. One such event was the NTNU AI Day on December 8th, where NAIL together with the IE faculty sought to expand the contributing departments in NAIL beyond the IE faculty and campus Gløshaugen. The event was streamed, allowing participants in Ålesund and Gjøvik to join in, and a workshop will be hosted to follow up this initative in the spring semester of 2024.

Web page: https://www.ntnu.edu/ailab

Impact case guidelines

Each case study should include sufficiently clear and detailed information to enable the evaluation committee to make judgements based on the information it contains, without making inferences, gathering additional material, following up references or relying on members' prior knowledge. References to other sources of information will be used for verification purposes only, not as a means for the evaluation committee to gather further information to inform judgements.

In this evaluation, impact is defined as an effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia.

Timeframes

- The impact must have occurred between 2012 and 2022
- Some of the underpinning research should have been published in 2012 or later
- The administrative units are encouraged to prioritise recent cases

Page limit

Each completed case study template will be limited to **five pages** in length. Within the annotated template below, indicative guidance is provided about the expected maximum length limit of each section, but institutions will have flexibility to exceed these so long as the case study as a whole remains no longer than **five pages** (font Calibri, font size 11). Please write the text into the framed template under the sections 1–5 below. The guiding text that stands there now, can be deleted.

Maximum number of cases permitted per administrative unit

For up to 10 researchers: one case; for 10 to 30 researchers: two cases; for 30-50 researchers: three cases; for 50-100 researchers: four cases, and up to five cases for units exceeding 100 researchers.

Naming and numbering of cases

Please use the standardised short name for the administrative unit, and the case number for the unit (1,2,3, etc) in the headline of the case. Each case should be stored as a separate PDF-document with the file name: [Name of the institution and name of the administrative unit] [case number]

Publication of cases

RCN plans to publish all impact cases in a separate evaluation report. By submitting the case the head of the administrative units consents to the publication of the case. Please indicate below if a case may not be made public for reasons of confidentiality.

If relevant, describe any reason to keep this case confidential:

Please write the text here

NTNU-IIK Impact Case 1

Institution: IIK
Administrative unit: NTNU-IIK-INF
Title of case study: Author Input Behavioural Analysis (AIBA)
Period when the underpinning research was undertaken: Idea 2016, first results 2019, ongoing
Period when staff involved in the underpinning research were employed by the submitting institution: full period
Period when the impact occurred: full period

1. Summary of the impact

The research on early cyber grooming detection had led to the establishment of a spin-off company AIBA AS on the 1st of April 2022. The goal of the research was to protect children in online forums from sexual predators by developing an early warning system based on behavioural biometrics. The company currently has 10 employees and is growing. Customers include gaming companies as well as law enforcement.

2. Underpinning research

Research on cyber grooming detection had a big boost in 2012 with the PAN2012 cyber grooming competition. The goal of that competition was to detect sexual predators, based on full conversations. The research we performed was actually on early detection of cyber grooming conversations and groomer behaviour. The research started with a master thesis work in 2019, were the student first had the same goal as for the PAN2012 competition, but also tested the early detection. These results were the first in early detection and the test showed that we could detect cyber grooming after on average less than 40 messages, where the conversations were on average well over 3000 messages long. Other master students worked specifically with the goal of early detection in the conversations, bringing the number of messages needed for detection even further down.

A different approach was taken in another master students thesis work, where we looked at anomalous behaviour in a chat environment. In this case there was a focus on messaging behaviour, connections between chat partners and alike. The results of this work showed that we could indeed detect anomalous behaviour in chats, but that not all anomalous behaviour was due to cyber groomers. All of the detected anomalous behaviour was however unwanted (spamming, grooming, etc.). While the initial student work focussed on the possibilities for anomalous detection in long term behaviour of a person, did follow up research of a master thesis student again focus on early detection.

Besides various master and bachelor thesis works, there was also a PhD student working on the same topic for her thesis, with a focus on both analysis of keystroke dynamics and text analysis to combine fake profile detection with cyber grooming detection.

Main researchers involved are Prof. Patrick Bours (1/2016-ongoing), Dr. Parisa Rezaee Borj (PhD work, 11/2017 – 10/2022), Dr. Muhammad Ali Fauzi (PhD course work, fall 2019). Furthermore the following MSc students have been involved: Halvor Kulsrud (spring 2019), Jørgen Bendiksen (fall 2019), Lara Raffel (spring 2020), Marit Sylstad (spring 2021), Nakul Pathak (spring 2021), Joakim Granli Antonsen (fall 2021), Anna Fridtun Aarekol (spring 2022), Iselin Eriksen Eng (spring 2023), Dharshini Tharmarajan (spring 2023), Jan Luo Tang (spring 2023), Simen Melleby Aarnseth (spring 2023), Kevin Barhaugen (spring 2023), Marius Valen (fall 2023), Trond Stien (fall 2023), Kristian Havstein (fall 2023), Silje Bjørnstad Martinsen (spring 2024), Johanne Kaatorp and Benjamin Dybvik (spring 2024), Mathias Øveren Enger (spring 2024), Lise Marie Brekke Nilsen and Johanne Rønneberg (spring 2024), Jan-Simon Köhnke (spring 2024)

3. References to the research (indicative maximum of six references)

1. P. Bours and H. Kulsrud, "Detection of Cyber Grooming in Online Conversation," 2019. IEEE International Workshop on Information Forensics and Security (WIFS), Delft, Netherlands, 2019, pp. 1-6, doi: https://doi.org/10.1109/WIFS47025.2019.9035090
2. M. A. Fauzi and P. Bours, "Ensemble Method for Sexual Predators Identification in Online Chats," 2020. 8th International Workshop on Biometrics and Forensics (IWBF), Porto, Portugal, 2020, pp. 1-6, doi: https://doi.org/10.1109/IWBF49977.2020.9107945
3. M.A. Wani, N. Agarwal, and P. Bours, "Sexual-predator Detection System based on Social Behavior Biometrics (SSB) Features," 2021. Procedia Computer Science, Vol. 189, pp. 116-127, doi: https://doi.org/10.1016/j.procs.2021.05.075
4. A.F. Aarekol, "A graph theoretical approach to online predator detection," 2022. Master thesis NTNU, https://hdl.handle.net/11250/3014533
5. P.R. Borj, K. Raja, and P. Bours. "Online grooming detection: A comprehensive survey of child exploitation in chat logs," 2023. Knowledge-Based Systems, Vol. 259, pp. 1-21, doi: http://dx.doi.org/10.1016/j.knosys.2022.110039
6. I.E. Eng, "Dynamic graph theoretical analysis of cybergrooming detection in chatrooms," 2023. Master thesis NTNU

4. Details of the impact

Cyber grooming is a growing problem with more and more children spending time online. According to the police the number of cases has been doubling every year for the last 5 years. 1 in 7 children has been contacted online by a sexual predator. Such contacts end in many cases in either online sexual abuse, sextortion or even physical meetings between children and sexual predators. Detection of online grooming is of vital importance to protect these vulnerable members of society. Research into detection of cyber grooming has long concentrated only on forensic (after the fact) detection. Our research was the first to investigate an early detection mechanism, such that children, gaming companies, or even the police, could be warned of ongoing cyber grooming activities and these could be stopped before any harm is done to these children.

The current solution is an analysis method that can determine the risk that an ongoing chat is cyber grooming and can, based on that, warn a moderator of an online game of any elevated risks. By using this method, there is no need to store full conversations, yet the risk is based on the full conversation. At a gaming company or chat provider, who has access to the full conversation, a moderator can review the conversations that are marked as highly risky, and this human can then decide if this is a cyber grooming conversation or not. In addition, the human moderator can determine which of the chat partners is the predator and who is the victim. This human-in-the-loop concept ensures that nobody is accused based only on the outcome of an ML model. The current way moderators work is that they either review randomly selected conversations or focus on conversations reported by users.

The same technique can be used in a police investigation, where a huge amount of chat messages is collected from the electronic devices of a suspect. The ML model can quickly indicate which conversations, or which parts of conversations are most relevant for the investigation. The current alternative is that a police officers manually reads through these chat logs, which takes too long time.

5. Sources to corroborate the impact

- Police Academy Norway (PHS): Prof. Inger Marie Sunde
- AIBA AS: Hege Tokerud (CEO)
- AIBA AS: Gard Støe (CTO)
- MovieStarPlanet ApS: Vernon Jones (Head of Safety and Support)

Impact case guidelines

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In this evaluation, impact is defined as an effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia.

Timeframes

- The impact must have occurred between 2012 and 2022
- Some of the underpinning research should have been published in 2012 or later
- The administrative units are encouraged to prioritise recent cases

Page limit

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Publication of cases

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If relevant, describe any reason to keep this case confidential:

Please write the text here

NTNU-IIK Impact Case 2

Institution: NTNU
Administrative unit: IIK
Title of case study: User-centric service delivery
Period when the underpinning research was undertaken: 2012-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2012-2022
Period when the impact occurred:2020 - 2022

1. Summary of the impact

This impact case describes efforts to improve user-centric service delivery with emphasis on HTTP-adaptive video streaming. Several optimization methods are suggested and validated allowing video streaming providers and network providers to improve system and energy efficiency and reduce operational costs. The generated impact is acknowledged by two network providers and a vendor as relevant impact during the pre-standardization phase.

2. Underpinning research

Every day, billions of people use platforms such as YouTube, Netflix, or Amazon to stream videos and movies on their smartphones, computers, tablets, or televisions. The individual transmission over the Internet, also known as Video-on-Demand (VoD) streaming, is realized through Dynamic Adaptive Streaming over HTTP (DASH). This method, which allows the video quality to dynamically adapt to the existing conditions of the service infrastructure, namely the transmission networks and end devices, was developed over 10 years ago. However, despite extreme usage and technological maturity, video streaming still presents a significant challenge for video and network providers. Due to the multitude of different end devices, network types, network providers, and video providers, as well as a variety of individual optimization possibilities, a large and - in practice - not entirely comprehensible parameter space arises. Although over-provisioning is a viable solution, this typically results in an inefficient usage of the available network resources as well as high capital and operational expenditures. Therefore, user-centric networking has emerged as new concept aiming at a high utilization of the network resources while simultaneously providing a Quality of Experience (QoE). The idea of this concept is to control the network resources based on key application quality indicators, therefore increasing the system complexity.

The conducted underpinning research focused on (i) the appropriate parametrization of control knobs on video service and network level, and (ii) the design and validation of novel mechanisms focusing on user-centric service delivery and thus to improve video delivery, system utilization, and user-perceived quality. The underlying research can be categorized in the following three areas:

DASH-based video streaming (P. Heegaard, 2012- 2013, T. Zinner 2019 - 2020)
DASH-based systems allow to adjust the played back quality during the streaming sessions with respect to the available network and system resources. This is achieved by having fixed length video segments with multiple different qualities. The idea of providing the video content additionally in segments of different durations, was introduced in [1]. The idea was extended to variable segment durations in [3], taking the video content characteristics into account.
Through the new approach, bitrate can be significantly reduced in parts, without visibly affecting video quality and the QoE. On average, a reduction of 7% is achieved, with individual videos experiencing reductions of over 15%.

QoE monitoring in 5G (T. Zinner 2019 – 2022)
Network providers have various options to optimize video streaming, but a solid understanding of the streaming application and the user-perceived QoE is needed to use these mechanisms in a

meaningful way. In [5] a mechanism allowing to learn and predict video QoE from network telemetry data embedded in the 5G systems is proposed and validated. A cost-benefit analysis indicates the importance of specific monitoring parameters, such as the average throughput, while other data, like packet delay, provide relatively lower value for the accuracy of estimation.

QoE-aware network control (P. Heegaard 2017-2018, T. Zinner 2019 – 2022, M. Gajic 2019 - 2022) Mechanisms like TCP and best-effort packet delivery results in a fair distribution of network resources with respect to Quality-of-Service among multiple users, but also lead to QoE variations in case of diverging application requirements. Although various resource control mechanisms are available it has remained a challenge to identify and parameterize the appropriate ones. [2] tackles the question whether it is generally worth to introduce additional complexity introduced by these mechanisms and concludes the general applicability of the concept. A concrete case for multiple different applications with focus on video streaming applications is conducted in [4]. The proposed mechanism utilizes 5G QoS mechanisms and is capable to increase the number of admitted clients while preserving the QoE.
A conceptual analysis of how to realize QoE-aware network control for interconnected networks is conducted in [6]. Reasons for being locked into the status quo and a roadmap to overcome the lock-in proposing specialized connectivity services is provided.

Research in the mentioned areas was conducted by:

- Poul Heegaard, Professor, permanently employed at the administrative unit during the evaluation period.
- Thomas Zinner, Assoc. Prof 2019-2022 / Prof since 2022, permanently employed at the administrative unit since 2019.
- Marija Gajic, PhD student 2019 – 2022 / Assistant Professor since 2022, permanently employed at the administrative unit since 2022.

3. References to the research (indicative maximum of six references)

1] Bjørn Villa, Poul Heegaard, “HTTP video streaming by segment duration control,” 2013, IEEE 27th International Conference on Advanced Information Networking and Applications (AINA), https://doi.org/10.1109/AINA.2013.9

[2] Christian Moldovan; Lea Skorin-Kapov; Poul E. Heegaard; Tobias Hoßfeld, “Optimal Fairness and Quality in Video Streaming with Multiple Users,” 2018, 30th International Teletraffic Congress (ITC 30), https://doi.org/10.1109/ITC30.2018.00018

[3] Susanna Schwarzmann, Nick Hainke, Thomas Zinner, Christian Sieber, Werner Robitza, Alexander Raake, “Comparing fixed and variable segment durations for adaptive video streaming: a holistic analysis,” 2020, 11th ACM Multimedia Systems Conference, https://dl.acm.org/doi/proceedings/10.1145/3339825

[4] Marcin Bosk; Marija Gajić; Susanna Schwarzmann; Stanislav Lange; Riccardo Trivisonno; Clarissa Marquezan; Thomas Zinner, “Using 5G QoS Mechanisms to Achieve QoE-Aware Resource Allocation,” 2021, 17th International Conference on Network and Service Management (CNSM) 10.23919/CNSM52442.2021.9615557

[5] Susanna Schwarzmann, Clarissa Marquezan, Riccardo Trivisonno, Shinichi Nakajima, Vincent Barriac and Thomas Zinner, "ML-Based QoE Estimation in 5G Networks Using Different Regression Techniques," 2022, IEEE Transactions on Network and Service Management, https://doi.org/10.1109/TNSM.2022.3179924

[6] Håkon Lønsethagen , Stanislav Lange , Thomas Zinner , et al. Towards Smart Public

Interconnected Networks and Services -- Approaching the Stumbling Blocks, 2022, TechRxiv, https://doi.org/10.36227/techrxiv.19690570.v1

4. Details of the impact (indicative maximum 750 words)

The generated impact is on designing and validating mechanisms to optimize the video-streaming eco-system. Based on recent reports by Cisco, video streaming denotes to more than 80% of the global Internet traffic, and already small optimizations can have a large impact on the key operational constraints (costs, energy consumption, number of devices) of service, network and digital infrastructure providers in line with the sustainable development goal 9: Industry, innovation and infrastructure. In the following the specific impact on the three research areas in section 2 of this case are summarized.

DASH-based video streaming: The administrative unit was involved is a thorough investigation reasonably proofing that variable segment durations generally reduce resource requirements by 7% on average without visible degradation of the video streaming experience. While the investigated mechanism had been proposed earlier, an assessment of its impact with the dash.js reference implementation in a realistic environment had not been conducted yet.

The research was disseminated as paper [3] in 2020. The research was conducted together with researchers from TU Berlin (study implementation and data analysis), TU Munich (study implementation), and TU Ilmenau (video encoding and validation). The main author was PhD student at TU Berlin, supervised by Thomas Zinner. TU Berlin conducted the studies and analysed the data. The researcher from TU Munich, a former master student of Thomas Zinner, contributed to the system implementation. The researchers from TU Ilmenau contributed to and validated the video encoding process. Thomas Zinner contributed with the main idea, scientific guidance, and the supervision of the main author.

The paper received the “Excellence in DASH-Award” of the DASH industry forum consisting of major players like Apple, Microsoft or Netflix in 2020. This award is given to practical enhancements and developments which can sustain future commercial usefulness of DASH.

QoE monitoring in 5G: The conducted analyses and considerations are based on a collaboration with a network provider and an equipment vendor and provide a practical guide for integrating QoE measurement into 5G networks. The presented QoE monitoring approach exclusively utilizes already available 5G network functions and can thus be deployed in operational networks without further preparatory work. By obtaining reliable QoE estimations, the network provider can finely adjust its control mechanisms, thereby ensuring a better streaming experience for the user while optimizing the utilization of existing network resources.

The research was disseminated as paper [5] in 2022. The research was conducted together with researchers from TU Berlin, Huawei, and Orange. The main author, a PhD student from TU Berlin, has been supervised by Thomas Zinner. Another postdoctoral researcher from TU Berlin assisted in validated the machine learning approach. The researchers from Huawei contributed to the 5G system design, and the researchers from Orange contributed to the investigated use-cases. Both industrial partners further assured the practical relevance of the conducted research. Thomas Zinner contributed with the main idea, scientific guidance, and the supervision of the main author. All authors were involved in writing the paper.

The conducted research confirmed for Orange the viability of statistical tools for QoE prediction and resulted in a larger study started mid of 2022. The outcome of the study by Orange are models which, upon a positive decision, will be implemented in a laboratory environment in 2025. In the

case of Huawei, the conducted research contributed to knowledge acquisition and supported several pre-standardization and 3GPP standardization activities.

QoE-aware network control: The conducted analyses and considerations are based on a collaboration with an equipment vendor and are based on realistic assumptions of public 5G deployments. The presented QoE-aware resource allocation using 5G QoS mechanisms can increase the number of admitted users without affecting the user-perceived application quality. This results in a higher economic efficiency and a reduced energy consumption per user.

The research was disseminated as paper [4] in 2021 and paper [6] in 2022. The research in [4] was conducted together with researchers from TU Munich and Huawei. The main authors are a PhD student from the administrative unit and a PhD student from TU Munich. The researcher from TU Munich contributed to the simulation environment and the system implementation. The industrial partner assured the practical relevance of the conducted research. Thomas Zinner contributed with the main idea, scientific guidance, and the supervision of the main author. The research in [6] was conducted together with researchers from Telenor, Thales, Telefonica, and Nextworks. The idea was jointly developed by the researchers from Telenor and NTNU. The researcher from Telenor took the main responsibility to further shape the paper and integrated additional industrial partners to broaden the perspective of the research topic. The researchers from NTNU provided critical reflections and discussions and conducted the evaluation study.

During the conducted research a hierarchical token bucket filter was implemented into the OMNET++ simulation environment to enable traffic shaping. This implementation was integrated into the main branch of the OMNET++ INET framework in 2021.

The results of [4] and [6] were disseminated to Telenor during an internal workshop in August 2022 and is followed up Telenor internally and by Telenor to SNS JU and 6G-IA.

5. Sources to corroborate the impact (indicative maximum of ten references)

Dash-based video streaming:

Link to DASH IF Award 2020: https://multimediacommunication.blogspot.com/2020/06/dash-if-awarded-excellence-in-dash.html

QoE monitoring in 5G:

Link to the paper (co-authors from industry)**: https://ieeexplore.ieee.org/document/9786853**
Letter of Support from Orange (V. Barriac) and Huawei (R. Trivisonno), attached to this document.

QoE-aware network control:

Link to paper [4] (co-authors from industry): **https://ieeexplore.ieee.org/document/9615557**
Link to paper [6] (co-authors from industry):
https://www.techrxiv.org/doi/full/10.36227/techrxiv.19690570.v1

Link to the HTB implementation in the Omnet++ repository**:** inet-gpl/src/inetgpl/queueing/scheduler/HtbScheduler.cc at master · inet-framework/inet-gpl · GitHub
Letter of Support from Telenor (H. Lønsethagen), attached to this document.

Impact case guidelines

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In this evaluation, impact is defined as an effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia.

Timeframes

- The impact must have occurred between 2012 and 2022
- Some of the underpinning research should have been published in 2012 or later
- The administrative units are encouraged to prioritise recent cases

Page limit

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Publication of cases

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If relevant, describe any reason to keep this case confidential:

Please write the text here

NTNU-IIK Impact Case 3

Institution: NTNU
Administrative unit: IIK
Title of case study: Isogeny Based Cryptography
Period when the underpinning research was undertaken: 2012, 2021, 2022, ongoing
Period when staff involved in the underpinning research were employed by the submitting institution: 2012, 2013, 2021 - ongoing
Period when the impact occurred: 2013 – 2017, 2021 - ongoing

1. Summary of the impact

Isogeny-based cryptography was (co)invented by a member of our research group. It offers a direct drop-in replacement for the old discrete-logarithm-based public key cryptography. The doctoral thesis "Cryptographic Schemes Based on Isogenies" by Anton Stolbunov, submitted in January 2012 [1], was a culmination of the research that Stolbunov performed initially during his master's studies and later at NTNU on his PhD studies.

2. Underpinning research

Post-Quantum Cryptography (PQC) focuses on creating cryptographic systems that can withstand attacks from quantum computers. Today's cryptographic systems are based on complex mathematical problems such as integer factorization and discrete logarithms, which could be solved relatively easily by a powerful quantum computer. In anticipation of this, cryptographers are developing new algorithms to resist quantum computing attacks. The research in PQC is primarily centred around six different methodologies: 1. Lattice-based cryptography, 2. Multivariate cryptography, 3. Hash-based cryptography, 4. Code-based cryptography, 5. Isogeny-based cryptography, and 6. Symmetric key quantum resistance.

The only methodology that can offer a direct drop-in replacement for the old discrete-logarithm-based public key cryptography is Isogeny-based cryptography, while the algorithms developed with all other methodologies have significantly larger data footprints such as public keys, private keys, ciphertexts or digital signatures.

The security of Isogeny-based cryptography relies on the problem of finding an explicit isogeny between two given isogenous elliptic curves over a finite field $\mathbb{F}_q$. Researchers noticed that quantum computers cannot solve the isogeny-finding problem easily.

The first proposal of an isogeny-based cryptosystem was made by Couveignes in 1997 [2]. It described a non-interactive key exchange protocol where the space of public keys equals the set of $\mathbb{F}_q$-isomorphism classes of ordinary elliptic curves over $\mathbb{F}_q$ whose endomorphism ring is a given order O, in an imaginary quadratic field and whose trace of Frobenius has a prescribed value.

However, as described in [3], the Couveignes' work was only circulated privately and thus not picked the attention of the cryptographic community; the corresponding paper [2] was never formally published and was posted on ePrint only in 2006, after the publication of the Stolbunov's master's thesis [4]. The scheme in [4] is nowadays depicted as Couveignes–Rostovtsev–Stolbunov scheme.

3. **References to the research** (indicative maximum of six references)

[1] Stolbunov, A.: *Cryptographic schemes based on isogenies*. Ph.D. thesis, Norwegian University of Science and Technology (2012). https://ntnuopen.ntnu.no/ntnu-xmlui/bitstream/handle/11250/262577/529395_FULLTEXT01.pdf

[2] Couveignes, J.-M.: Hard homogeneous spaces. IACR Cryptology ePrint Archive 2006/291 (2006). https://ia.cr/2006/291

[3] Castryck, W., Lange, T., Martindale, C., Panny, L., Renes, J. (2018). *CSIDH: An Efficient Post-Quantum Commutative Group Action*. In: Peyrin, T., Galbraith, S. (eds) Advances in Cryptology – ASIACRYPT 2018. ASIACRYPT 2018. Lecture Notes in Computer Science(), vol 11274. Springer, Cham. https://doi.org/10.1007/978-3-030-03332-3_15

[4] Rostovtsev, A., Stolbunov, A.: *Public-key cryptosystem based on isogenies*. IACR Cryptology ePrint Archive 2006/145 (2006). https://ia.cr/2006/145

[5] De Feo, L., Kohel, D., Leroux, A., Petit, C., Wesolowski, B. (2020). *SQISign: Compact Post-quantum Signatures from Quaternions and Isogenies*. In: Moriai, S., Wang, H. (eds) Advances in Cryptology – ASIACRYPT 2020. ASIACRYPT 2020. Lecture Notes in Computer Science(), vol 12491. Springer, Cham. https://doi.org/10.1007/978-3-030-64837-4_3

[6] Jorge Chavez-Saab, Maria Corte-Real Santos, **Jonathan Komada Eriksen**, Basil Hess, David Kohel, Antonin Leroux, Patrick Longa, Michael Meyer, Lorenz Panny, Sikhar Patranabis, Christophe Petit, Francisco Rodríguez Henríquez, Sina Schaeffler, Benjamin Wesolowski, *SQISign, Algorithm specifications and supporting documentation*, NIST, 1 June 2023, https://csrc.nist.gov/csrc/media/Projects/pqc-dig-sig/documents/round-1/spec-files/sqisign-spec-web.pdf

[7] Steven Galbraith, "*Breaking supersingular isogeny Diffie-Hellman (SIDH)",* The Elliptic Curve Cryptography blog, 31 July 2022, https://ellipticnews.wordpress.com/2022/07/31/breaking-supersingular-isogeny-diffie-hellman-sidh/

4. Details of the impact

In 2012, one of the members of the PhD evaluation committee for Stolbunov's doctoral thesis [1] was Prof. Tanja Lange from the Technical University of Eindhoven, Netherlands. As an expert in elliptic curve cryptography, she became familiar with Stolbunov's work in Isogeny based cryptography.

Several years later, in 2018, together with several co-authors [3], they proposed the isogeny based key-exchange scheme CSIDH. As described in [3] :
"*In this paper we show that adapting the Couveignes–Rostovtsev–Stolbunov scheme to supersingular elliptic curves is possible, provided that one restricts to supersingular elliptic curves defined over a prime field* $\mathbb{F}_q$*. Instead of the full ring of endomorphisms, which is non-commutative, one should consider the subring of* $\mathbb{F}_q$*-rational endomorphisms, which is again an order O in an imaginary quadratic field. "*

Then in 2020 isogeny based post-quantum signature scheme SQISign was proposed [5]. While the initial proposal has superiorly smaller signatures in comparison with other post-quantum algorithms, the scheme was very slow. Then, several researchers started to work on improving the efficiency of the scheme. Among them was the current member of the Cryptology Discipline, Jonathan Komada Eriksen. His contributions to SQISign efficiency were recognized by the SQISign team and he was invited to join them in the submission to the NIST Post-Quantum Signatures standardization process [6].

Isogeny based cryptography is a developing research area in Cryptography. While one other isogeny based scheme - SIDH - was broken in 2022, the broader cryptographic community and the experts in the isogeny based cryptography such as Stephen Galbraith, expressed the opinion that the attack is not applicable to CSIDH and SQISign.

5. Sources to corroborate the impact

- Luca De Feo, IBM Research Zürich, Switzerland, email: eurocrypt23@defeo.lu
- Tanja Lange, Department of Mathematics and Computer Science, Technische Universiteit Eindhoven, The Netherlands, email: tanja@hyperelliptic.org
- Steven Galbraith, Head of Department, Mathematics Department, Cyber Security Foundry, University of Auckland, New Zealand, email: S.Galbraith@auckland.ac.nz

Impact case

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Timeframes

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If relevant, describe any reason to keep this case confidential:

Please write the text here

NTNU-IIK Impact Case 4

Institution: Norwegian University of Science and Technology (NTNU)
Administrative unit: Department of Information Security and Communication Technology (IIK)
Title of case study: Raising Higher Education in Information Security to a mainstream education program at the bachelor, master's and doctoral levels
Period when the underpinning research was undertaken: 2012-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2012-2022
Period when the impact occurred: 2016- (major increase in number of students)

1. Summary of the impact (indicative maximum 100 words)
This section should briefly state what specific impact is being described in the case study.

The first information security master program in Norway was developed by members of the unit starting as back as in 1998 with dramatic expansion from 2012-2016. The program was developed through cooperation with the Royal Institute of Technology in Stockholm, Sweden. The program was first a small niche program but has expanded to the **largest provider** of academic education in **cybersecurity** in Norway with a total intake of over 250 students at the bachelor, master and doctoral level in information and cyber security each year.

2. Underpinning research (indicative maximum 500 words)

This expansion and ongoing development of study programs were driven through research-based teaching with many publications, experiments, and innovations in cybersecurity education in general, with specialization in cyber ranges [1], simulations [2], and serious games [6].
The research focused on developing curriculum modelling of core threshold concepts in information security and risk management education, followed by experimenting with state-of-the-art technologies [2-5] to deliver and measure its effectiveness on a diverse group of students with different backgrounds and work experiences.
Another relevant example is related to AI Chatbots [5], which, along simulations and serious games, were used to support the students and other relevant target groups in understanding information security management and risk management from a holistic and socio-technical approach.

Key contributors:

- Stewart Kowalski
  - Vice Dean of Education Computer and Media Technology (HIG 2013-2016),
  - Professor 2016-2022
  - Academic Head, Norwegian Cyber Range Project 2018-2022

Stewart helped establish the Norwegian cyber range from 2018-2022 using a top-down socio-technical approach.

- Einar Arthur Snekkenes
  - Professor in Information Security

Einar has been a Professor in Information Security 2002, his special focus being on information security risk management.

- Gaute Wangen
  - PhD in Information Security, 2013-2017
  - Postdoctoral Researcher, 2016-2017
  - Assistant Professor, 2021
  - Associate Professor II, 2022

Gaute has been an active member of the group since after his enrollment in the PhD program. His research focuses on risk management tools and standards

- Erjon Zoto
    - Postdoctoral Researcher, 2017-2018
    - Assistant Professor in Cybersecurity & IT Management, 2019-2022

Erjon has contributed in developing simulation tools for supporting cyber security education and training among different target groups.

- Grethe Østby
    - PhD student, 2018-2022

Grethe has expanded the usage of the Cyber range facilities with her experience in military and crisis management exercises

- Mazaher Kianpour
    - PhD student, 2018-2022

Mazaher has contributed to research related to the usage of serious games in cyber ranges.

3. References to the research (indicative maximum of six references)

1. Katt, B. and Kowalski, S. (2021) 'Hybrid Cyber Range'. Available at: https://doi.org/10.1007/978-3-642-27739-9_1583-1
2. Zoto, Erjon; Kowalski, Stewart James; Lopez Rojas, Edgar Alonso; Kianpour, Mazaher. (2018) Using a socio-technical systems approach to design and support systems thinking in cyber security education. *CEUR Workshop Proceedings*
3. Wangen, Gaute; Hallstensen, C.; Snekkenes, Einar (2017) A framework for estimating information security risk assessment method completeness: Core Unified Risk Framework, CURF. *International Journal of Information Security, 17, 681-699. (CI: 123)*
4. Nowostawski, Mariusz; Kowalski, Stewart; Mwakalinga, Jeffy. (2015) HIPing Innovation Education in University: Introducing socio-technical concepts for cross-disciplinary teams in applied computer sciences. *CEUR Workshop Proceeding*
5. Kowalski, S., Pavlovska, K., Goldstein, M. (2013). Two Case Studies in Using Chatbots for Security Training. In: Dodge, R.C., Futcher, L. (eds) Information Assurance and Security Education and Training. WISE 2013. IFIP Advances in Information and Communication Technology, vol 406. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-39377-8_31
6. Sikkerhetsfestivalen 2019. Stewart Kowalski, Grethe Østby. *Workshop*, Lillehammer

4. Details of the impact (indicative maximum 750 words)

There is an acute shortage of cybersecurity professionals in the world in general, with some estimates reaching over 4 million[1]. Norway has been affected from these developments as well, which brought the unit members in Gjøvik to work together for addressing the issue.

During the past 10 years, the ongoing research from the unit members, coupled with multiple years of work experience in academia helped establish, expand and further innovate the teaching methods used, hence the study programs overall, for providing high-quality education to students at all levels in HIG and then at NTNU Gjøvik [1].

This process helped create a unique source of successful candidates for the local job market, with almost half of undergraduate students successfully hired before their final graduation on a yearly basis. The remaining students were then able to get a relevant job in security or IT management within the next 2 years, while they were fulfilling their master studies.

[1] https://www.csoonline.com/article/657598/cybersecurity-workforce-shortage-reaches-4-million-despite-significant-recruitment-drive.html

During their study years in Gjøvik, students at all levels were engaged in local, national, and international competitions, coached and supported from several members of our unit on a yearly basis. Examples of such competitions include the Cyber 9/12 Challenge [2], the National Cybersecurity Challenge [3], and the European Cybersecurity Challenge [4], among others. Ongoing feedback received was very positive regarding the methods used, which were highly engaging and successful in getting the students to achieve their learning objectives within a short time.

Further on, the National Cyber Range (NCR) was established in September 2018 [5], with the Gjøvik representatives of the unit present as leading roles in the research and education sections, during and after its establishment.

The NCR was further used in multiple cases for cyber range exercises, involving target groups representing several sectors, ranging from hospitals to central agencies, further on to the local government.

All activities related to the NCR helped improve teaching methods towards our students [6], as well as creating the basis for ongoing dissemination in the form of interviews [7], invited guest lectures [8], online training and exercises [9], as well as physical workshops organized as role-playing serious games [10], all of them with the main aim towards improving cybersecurity awareness and training among different target groups within Norway and beyond.

5. Sources to corroborate the impact (indicative maximum of ten references)

1. Database for statistikk om høyere utdanning, LINK: https://dbh.hkdir.no/
2. Cyber 9/12 Strategy Challenge, link: https://www.atlanticcouncil.org/programs/digital-forensic-research-lab/cyber-statecraft-initiative/cyber-912/
3. Norwegian Cybersecurity Challenge, link: https://www.ntnu.no/ncsc
4. European Cybersecurity Challenge, link: https://www.ecsc2022.eu/
5. Norwegian Cyber Range, link: https://www.ntnu.no/ncr
6. Østby, G. and Kowalski, S.J., 2022. Introducing Serious Games as a Master Course in Information Security Management Programs: Moving Towards Socio-Technical Incident Response Learning. In *Handbook of Research on Cross-Disciplinary Uses of Gamification in Organizations* (pp. 483-506). IGI Global.
7. Zoto, Erjon. (2019) Advarer mot svak norsk cybersikkerhet. *Dagens Næringsliv* Dagens Næringsliv [Newspaper] 2019-09-12
8. Erjon Zoto, Stewart J. Kowalski, 2022. Using a socio-technical systems approach to design and support systems thinking in cyber security education. *Webinar presentation* - Purdue Systems Thinkers, Purdue University, Indiana, USA
9. https://ovelse.no/
10. Sikkerhetsfestivalen 2022. Stewart Kowalski, Eduard von Seth, Erjon Zoto. *Workshop,* Lillehammer

NTNU-IMF 1

Institution: NTNU
Administrative unit: NTNU-IMF (Department of Mathematical Sciences)
Title of case study: Smittestopp appen
Period when the underpinning research was undertaken: 2020
Period when staff involved in the underpinning research were employed by the submitting institution: 2020
Period when the impact occurred: 2020

1. Summary of the impact

The Google/Apple interaction tracking system used during parts of the COVID pandemic was designed with privacy in mind, but the (national) system for uploading tracking data after infection was suboptimal from a privacy point of view, potentially leaking infection status. This research developed cryptographic constructions and implemented them. The impact significantly improved the privacy of this part of the system.

2. Underpinning research

The system for uploading tracking data consists of two actors: one system that knows which individuals are infected, and one system that manages the tracking data. Only infected people should be able to upload tracking data to the second system, which means that every upload must be authorised by the first system. However, the first system should not learn which tracking data belong to which person, while the second system should not learn to whom uploaded tracking data belongs.

A cryptographic tool that can be used to solve this problem is anonymous single-use tokens. The underpinning research was to develop improved such schemes, and also increase their functionality to include metadata.

Such tokens are typically based on blinded versions of zero knowledge proofs, where the issuer proves that the token has been correctly constructed.

The paper proposed a version based on the traditional discrete logarithm problem in suitable cyclic groups, which does not have public verifiability. The authors also propose a version based on groups with efficiently computable bilinear pairings (suitable elliptic curves over finite fields) which has public verifiability.

The work was done between late 2020 and early 2021.

The key researcher at IMF was Tjerand Silde, a PhD student at the time. The work was joint with Martin Strand of the Norwegian Defence Research Establishment (who graduated with a PhD from IMF in 2018).

3. References to the research

Tjerand Silde, Martin Strand: Anonymous Tokens with Public Metadata and Applications to Private Contact Tracing. Financial Cryptography 2022: 179-199. https://doi.org/10.1007/978-3-031-18283-9_9

4. Details of the impact

Silde and Strand, together with Henrik Walker Moe, implemented an extension for the Norwegian contact tracing system, based on single-use anonymous tokens, which was included in the deployed system.

This extension improved privacy of the overall contact tracing system. An earlier iteration of the system used an app that gathered too much personal data, which was eventually banned by the Norwegian Data Protection Authority. Showing that the new version had significantly improved privacy was important in order to be able to deploy the system.

The main impact consists of increased confidence in the privacy of the contact tracing systems. Since the contact tracing system relies on significant deployment to be effective, this is obviously crucial for effectiveness.

This software would not have been possible without the underpinning research.

5. Sources to corroborate the impact

Salathé M, Althaus C, Anderegg N, Antonioli D, Ballouz T, Bugnon E, Čapkun S, Jackson D, Kim SI, Larus J, Low N, Lueks W, Menges D, Moullet C, Payer M, Riou J, Stadler T, Troncoso C, Vayena E, von Wyl V. Early evidence of effectiveness of digital contact tracing for SARS-CoV-2 in Switzerland. Swiss Med Wkly. 2020 Dec 16;150:w20457. doi: 10.4414/smw.2020.20457. PMID: 33327003.

NTNU-IMF 2

Institution: NTNU
Administrative unit: NTNU-IMF (Department of Mathematical Sciences)
Title of case study: Short observation series and geostatistical methods improve Norwegian runoff maps
Period when the underpinning research was undertaken: Until 2020
Period when staff involved in the underpinning research were employed by the submitting institution: From 2008
Period when the impact occurred: From 2022

1. Summary of the impact

Runoff is a key variable in hydrology, but most areas in the world lack runoff measurements, and runoff must be estimated. The mean annual runoff is based on 30 years of data. However, in many catchments there are shorter records.

In Roksvåg et al (2020), a geostatistical model was developed that enabled short records to be used for estimating mean annual runoff. Further, a methodology for merging models enabling short records and process-based simulations were developed (Roksvåg et al., 2022).

In 2022, the Norwegian water resources and Energy Directorate (NVE) launched a new, gridded mean annual runoff map for Norway. NVE used the methodology for merging short records and process-based simulations of Roksvåg et al (2022) to produce these maps.

2. Underpinning research

Essential for the research underpinning the innovation was:

1) Long term collaboration between researchers in statistics and hydrology on uncertainty quantification and evaluation of runoff forecasts. One of the papers from this work is Engeland et al (2016). This was part of the research project *The hydrological crystal bowl* (2008-2015), a collaboration between Statkraft (hydro power producer), SINTEF Energy Research, NTNU and University of Oslo.
2) Long term work on Bayesian geostatistical models and methods for computational efficient inference. An example of research that was both motivated by the hydrological needs, developed new spatial models that gave insight in using replicates of spatial random effects and balanced realistic models and computational efficiency is Ingebrigtsen et al. (2015). The models and computational methodology are based in the INLA-SPDE approach introduced in Lindgren et al. (2011). Both these papers were results of the Research Council of Norway research project *Spatio-temporal modelling and approximate Bayesian inference* (2010-2014).

The PhD work by Thea Roksvåg is essential for the innovation, and she did her PhD as part of the Research Council of Norway research project *Knowledge Based Non-Stationary Modeling* (2016-2020). The statistical foundation for the methodology is described Roksvåg et al. (2021). A Bayesian geostatistical model for annual runoff that models several years of runoff simultaneously using both point observations (precipitation) and areal observations (catchment runoff) with two spatial fields was developed. Based on this research, the two field Bayesian geostatistical methodology was further developed and validated for estimating annual mean runoff using both long and short runoff timeseries. Prediction experiments with Norwegian runoff data, showed that with the new model, only one year of runoff data from a river could lead to considerable improvements in the 30-year mean annual runoff estimates for that river's drainage area (Roksvåg

et al.,2020). In Roksvåg et al (2022), a methodology for estimating mean annual runoff using both simulations from a process-based hydrological model, the HBV model, and runoff observations was presented. A goal was to develop models and inference methodology that were computationally feasible for operational use. Therefore, a two-step procedure was proposed. Step one is a preprocessing step for including short records of observed annual runoff. Step two uses a spatial varying coefficient approach such that the relationship between the covariate (simulations from the HBV model) and the response variable (observed mean annual runoff) can vary in the study area. The proposed approach outperformed the HBV model when predicting runoff for ungauged and partially gauged catchments with a reduction in RMSE of 20 % for ungauged catchments and 58 % for partially gauged catchments. For ungauged catchments the proposed framework also outperformed a purely geostatistical method.

Key researchers at IMF, NTNU:

- Thea Roksvåg, PhD candidate at IMF, NTNU 2016-2020
- Ingelin Steinsland, (Associate) Professor at IMF, NTNU 2008-
- Rikke Ingebrigtsen, PhD candidate at IMF, NTNU, 2010-2014
- Finn Lindgren, Post-doctoral fellow at IMF, NTNU, 2010-2012
- Håvard Rue, Professor at NTNU until 2015

3. References to the research

Engeland, K., Steinsland, I., Johansen, S.S., Petersen-Øverleir, A. and Kolberg, S. (2016) *Effects of uncertainties in hydrological modelling. A case study of a mountainous catchment in Southern Norway*, Journal of Hydrology, . https://doi.org/10.1016/j.jhydrol.2016.02.036 ,536, 147-160, 2016

Ingebrigtsen, R., Lindgren, F., Steinsland, I and Martino, S (2015), *Estimation of a non-stationary model for annual precipitation in southern Norway using replicates of the spatial field*, Spatial Statistics,https://doi.org/10.1016/j.spasta.2015.07.003 ,14, 338-364, 2015
Lindgren, F., Rue, H. and Lindström, J. (2011) *An explicit link between Gaussian fields and Gaussian Markov random fields: The SPDE approach* (with discussion). Journal of the Royal Statistical Society, Series B, https://doi.org/10.1111/j.1467-9868.2011.00777.x , 73.4 , pp. 423–498.

Roksvåg, T., Steinsland, I., and Engeland, K. (2020) Estimation of annual runoff by exploiting long-term spatial patterns and short records within a geostatistical framework, Hydrol. Earth Syst. Sci., 24, 4109–4133, https://doi.org/10.5194/hess-24-4109-2020 4109-2020, 2020.

Roksvåg, T., Steinsland, I., and Engeland, K (2021*) A two-field geostatistical model combining point and areal observations—A case study of annual runoff predictions in the Voss area*, Journal of the Royal Statistical Society Series C*, 70,4, https://academic.oup.com/jrsssc/article-abstract/70/4/934/7034001*, 2021

Roksvåg, T., Steinsland, I., and Engeland, K. (2022) A geostatistical spatially varying coefficient model for mean annual runoff that incorporates process-based simulations and short records, Hydrol. Earth Syst. Sci., 26, 5391–5410, https://doi.org/10.5194/hess-26-5391-2022, 2022

4. Details of the impact

Runoff is a key variable in hydrology, but most areas in the world lack runoff measurements, and runoff must be estimated. In Norway 90% of electrical energy comes from hydropower, and annual mean runoff give information about long term water, and hence also energy availability.

Furthermore, in Norway mean annual runoff is the most important predictor for runoff extremes (Engeland et al. 2020). These are used to design infrastructures that should handle floods of e.g. 100 or 200 years. Therefore, estimates of runoff extremes are essential for balancing social security and infrastructure costs. The mean annual runoff is based on 30 years. However, in some catchments there only exist 1, 3, 10 or 28 years of observations. These data records are referred to as short records. NVE is responsible for making gridded mean annual runoff maps for Norway. In the previous version launched in 2002, short records were omitted from the analysis. Omitting the short records that were considered too short reduced the number of observation locations with more than 50 %.

NVE launched a new, gridded mean annual runoff map for Norway in 2022 using the methodology for merging short records and process-based simulations of Roksvåg et al (2022).

The impact of using the methodology of Roksvåg et al. (2022) is quantified for each of the two steps in Beldring et al (2022). In step 1 where the geostatistical method is used for estimating the mean annual runoff for 492 (of 690) locations, i.e. for 71% of the locations. In step 2 the process-based simulations were corrected using the mean annual runoff obtained in step 1. Evaluated with cross-validation, this procedure reduced the root mean square error (RMSE) from 309 to 232, i.e. a reduction of 25% in RMSE for ungauged catchments.

The reseach was based on long term collaboration, and senior researcher at NVE, Kolbjørn Engeland, was co-supervisor of Thea Roksvåg. During her PhD work, Roksvåg had research visits at NVE. The original aim of the reseach was not utlization of short records nor to contribute to runoff maps. However, in discussions it became evident that it was both a potential of the models and methods proposed in Roksvåg et al. (2021) to utilise short records and an opportunity for implementation in runoff maps for NVE.

5. Sources to corroborate the impact

ECMI (European consortium for mathematics in industry) Blog: Short observation series and geostatistical methods improve Norwegian mean annual runoff maps, by Thea Roksvåg and Ingelin Steinsland, link.

The runoff map is available here.

The runoff map is available for estimating floods, low flow and inflow to hydropower production systems in present and future climates using the web based system NEVINA (nve.no). This tool is frequently used by consulting firms and hydropower production companies and have been accessed on average more than 80 times per day during 2022, with runoff from a total of more than 30000 individual catchments analyzed.

In Norwegian only:

NVE rapport nr 36/2022: Avrenningskart for Norge 1991-2020 , authors, *Stein Beldring, Kolbjørn Engeland, Erik Holmqvist, Anja Iselin Pedersen, Gusong Ruan, Carl Andreas Veie, Julien Cabrol,* link
(The report described how the runoff maps for Norway 1991-2020 were obtained, include references to the journal papers of Roksvåg et al (2022).)

NVE rapport nr 10/2020: Lokal og regional flomfrekvensanalyse, authors, *Kolbjørn Engeland, Per Glad, Byman Hikanyona Hamududu, Hong Li, Trond Reitan and Seija Maria Stenius, link*
(The report described recommendations for calculating design flood in Norway. The analyses, see Figure 21, shows that the mean annual runoff (Q_N) is the main contributor explaining the variance (46%).)

NTNU-IMF 3

Institution: NTNU
Administrative unit: NTNU-IMF (Department of Mathematical Sciences)
Title of case study: Geophysical data inversion in a probabilistic setting
Period when the underpinning research was undertaken: Until 2022
Period when staff involved in the underpinning research were employed by the submitting institution: From 1996
Period when the impact occurred: From 2003

1. Summary of the impact

Geophysical reservoir characterization is critical for understanding properties of the subsurface. The case studies described here focus on petroleum companies' workflows and petroleum domain research resulting from our statistics research on Bayesian inversion.

Supported by the Norwegian Research Council and companies, the Uncertainty in Reservoir Evaluation (URE) and Geophysics and Applied Mathematics for Exploration and Safe production (GAMES) projects have developed novel inversion methods. Measuring impact in applied domains is complicated, but during the projects we have chosen to evaluate impact by two success criteria:

- Continued economic support from petroleum companies,
- PhDs who graduate and obtain relevant jobs.

2. Underpinning research

Seismic waves and rock physics relations were established a long time ago. Along with regularization terms and data processing, they have been useful in geophysical data inversion. But as extractors seek improved oil recovery and aims to produce smaller volumes of resources near existing infrastructure, the modeling gets more sophisticated, and solutions are required at a finer scale. Reliable predictions and uncertainty quantification are then key to decision support systems. The topic of probabilistic inversion has hence grown substantially in recent years.

Early approaches to probabilistic inversion for reservoir characterization were not very successful because they intermixed interpretations and data in several steps of the inversion, leading to underestimation of uncertainty and biased predictions. In many ways, Buland et al. (2003) re-defined seismic inversion in a probabilistic setting: This Bayesian solution separates a) the likelihood model linking reservoir properties to the data, and b) the prior model containing geoscience belief and spatial correlations. This approach leads to a modular setup which is easily explainable and reproducible. The paper also introduced a linearized likelihood expression where a posterior solution is conjugate with a Gaussian prior for fast probabilistic inversion. The paper has been cited 1100 times.

Going beyond Gaussian solutions, Eidsvik et al. (2004) and Larsen et al. (2006) developed methods for probabilistic inversion to discrete variables of interest (geological facies or fluid saturation). This is critical for decision-making because operational strategies are based on volumetric calculations of oil and gas. Both papers have been cited more than 200 times.
The URE and GAMES projects have been funded 50 % from petroleum companies and 50 % from the Research Council of Norway. Key researchers:

- Henning Omre, Professor, Department of Mathematical Sciences, NTNU 1992-2022
- Håkon Tjelmeland, Professor, Department of Mathematical Sciences, NTNU 1997-

- Jo Eidsvik, Professor, Department of Mathematical Sciences, NTNU, 2005-
- 15 graduated and 3 ongoing PhD students in statistics (2012-2022).

Based at the Department of Mathematical Sciences, NTNU, the URE and GAMES projects deliver applied statistical research that is successful according to the following impact criteria:

a) Companies maintaining contact and providing economic support,
b) Training of PhD graduates in statistics who obtain relevant jobs.

For a), we have maintained user-contact and long-term collaborations with industry partners having bottle-neck problems where statistics can contribute with creative solutions. URE and GAMES have continued to get support, even during the oil price collapse (2014-16). By choice, the partners have been in Norway or nearby countries, facilitating communication and use-case collaboration (mainly from the North Sea).
For b), we have trained students in new statistical methods for challenging data from the industry, making them interesting for companies and beyond. Most graduates have gone to energy companies, continuing to use skills developed during their PhD. We further have long-term contact with the Norwegian Computing Centre, who has employed many PhD graduates as researchers.

3. References to the research

Buland, A., & Omre, H. (2003). Bayesian linearized AVO inversion. *Geophysics*, *68*(1), 185-198. https://doi.org/10.1190/1.1543206
Eidsvik, J., Avseth, P., Omre, H., Mukerji, T., & Mavko, G. (2004). Stochastic reservoir characterization using prestack seismic data. *Geophysics*, *69*(4), 978-993. https://doi.org/10.1190/1.1778241
Gineste, M., Eidsvik, J., & Zheng, Y. (2020). Ensemble-based seismic inversion for a stratified medium. *Geophysics*, *85*(1), R29-R39. https://doi.org/10.1190/geo2019-0017.1
Grana, D., Fjeldstad, T., & Omre, H. (2017). Bayesian Gaussian mixture linear inversion for geophysical inverse problems. *Mathematical Geosciences*, *49*, 493-515. https://doi.org/10.1007/s11004-016-9671-9
Larsen, A. L., Ulvmoen, M., Omre, H., & Buland, A. (2006). Bayesian lithology/fluid prediction and simulation on the basis of a Markov-chain prior model. *Geophysics*, *71*(5), R69-R78. https://doi.org/10.1190/1.2245469
Rimstad, K., Avseth, P., & Omre, H. (2012). Hierarchical Bayesian lithology/fluid prediction: A North Sea case study. *Geophysics*, *77*(2), B69-B85. https://doi.org/10.1190/geo2011-0202.1

4. Details of the impact

Since 2012, the URE and GAMES projects have continued to develop probabilistic inversion methods. The vision in the projects has been to

- provide creative mathematically-based solutions to recognized challenges in reservoir evaluation,
- develop methodologies for analysis of spatial and spatio-temporal phenomena.

Hence, while it has been important to refine mathematical representations to include more sophisticated features and data, and to develop fast scalable methods for Bayesian inference in spatial applications, it has also been essential to apply methods on relevant real-world datasets. Not only can this lead to industry impact, but with new data types and complex models it can also feed back into statistical methodological development. Also, being statisticians in the Department of Mathematical Sciences, it has been crucial for us to keep contact with company users and conduct relevant applied statistical research. University research labeled as applied has no value if it cannot be applied by users.
We focus on three key papers indicative of our case studies between 2012 and 2022:

- Rimstad et al. (2012) developed methods for 3-dimensional discrete inversion and applied this to seismic data from the Alvheim field in the North Sea (provided by Lundin).
- Grana et al. (2016) developed methods with a Gaussian mixture inversion and applied this to a North Sea field.
- Gineste et al. (2021) developed an ensemble-based inversion method for seismic waveform data and applied this to a dataset provided by partner BP.

The case studies demonstrate how URE and GAMES contribute to:

i) petroleum companies' workflows,
ii) basic methodology for petroleum research.

Related to i), partners in the URE and GAMES projects have gained insight and changed their workflows based on recent modeling, methodologies and algorithmic approaches for Bayesian geophysical inversion. As illustrated in the examples below, partners have taken up on our approaches and used it to generate economic benefits in the company via new cases. Our long-term connection with the Norwegian Computing Centre has further led to extended use of the research because ideas have been further developed by PhD graduates working as researchers there who continue developing software for industry.
Related to ii), the papers have sparked interest in the petroleum research community, beyond the ones who develop new statistical approaches. As statisticians, we regard this concept of providing basic methodology for the field domains as crucial for influencing the applied research community. The papers by Rimstad et al. (2012) and Grana et al. (2017) have been cited more than 100 times each. The more recent paper by Gineste et al. (2020) has been cited 15 times. Most of these citations are from petroleum-oriented journals.

Rimstad et al. (2012) demonstrated significant effects of spatially varying burial history at the Alvheim field. They predicted volumes of oil and gas in different zones of the reservoir, and re-established the belief that a part of the reservoir segment was filled with oil-sands rather than gas-sands, which entails a substantial economic difference. Both Tullow oil and BP used similar approaches to improved reservoir characterization (Avseth et al., 2014; Walker et al., 2016).

Grana et al. (2017) and other papers by PhD student Fjeldstad, showed benefits of a Bayesian inversion method using Gaussian mixture models. The approach relies on a discrete latent variable which induces mixture components in the reservoir properties, and this can clearly give more reliable inversion results leading to improved decision support systems. The work was much appreciated by partner companies and used by BP in Walker et al. (2023).

Gineste et al. (2020) developed an ensemble-based approach for seismic waveform inversion, where the assumptions of linearity in the likelihood models are no longer needed. Instead, it relies on Monte Carlo simulations from the prior model and the generation of synthetic geophysical datasets to estimate model-data correlations. The approach was picked up by partner company BP as illustrated in the case by Zheng (2023) used on a different data set.

The effect on partners from the research impact from the URE and GAMES projects is further evidenced by the continued support from partner companies for more than 25 years.
In terms of petroleum research visibility, Omre was co-chair of the EAGE Petroleum Geostatistics conference in 2007 and 2015. Eidsvik was co-chair of this conference in 2019 and 2023. The conference gathers 100-150 participants from industry, service companies and academia.

5. Sources to corroborate the impact

The impact case study by Rimstad et al (2012) was further used by e.g.

- Tullow Oil : Avseth, P, Veggeland, T. and Lehocki, I., 2014, Combined Burial History and Rock Physics Modeling of Quartz-Rich Sandstones – Norwegian Shelf Demonstrations. Paper presented at the 2014 SEG Annual Meeting, Denver, Colorado, USA, October 2014. https://onepetro.org/SEGAM/proceedings-abstract/SEG14/All-SEG14/79171
- BP : Walker, M., Grant, S., Connolly, P., & Smith, L. (2016). Stochastic inversion for facies: A case study on the Schiehallion field. *Interpretation*, *4*(3), SL9-SL20. https://doi.org/10.1190/INT-2015-0197.1

The impact case study by Grana et al (2017) was further used by e.g.

- BP : Walker, M., Paramo, P., Wolf, K., Zhang, J., Biswas, R., Decalf, C., ... & Warnick, R. (2023, June). Gaussian Mixture Models as Priors in a Gradient-Based Variational Algorithm for Bayesian Elastic Inversion. In *84th EAGE Annual Conference & Exhibition* (Vol. 2023, No. 1, pp. 1-5). European Association of Geoscientists & Engineers. https://doi.org/10.3997/2214-4609.202310499

The impact case study by Gineste et al. (2020) was further used by e.g.

- Zheng, Y. (2021, October). Elastic Seismic Inversion Using an Iterative Ensemble Kalman Filter. In *82nd EAGE Annual Conference & Exhibition* (Vol. 2021, No. 1, pp. 1-5). European Association of Geoscientists & Engineers. https://doi.org/10.3997/2214-4609.202011763

Other case studies by URE and GAMES PhD students with relevant data from industry partners:

Forberg, O. B., Kjøsnes, Ø., & Omre, H. (2021). Bayesian seismic amplitude variation with offset inversion for reservoir variables with bimodal spatial histograms. *Geophysics*, *86*(3), R331-R350. https://doi.org/10.1190/geo2020-0086.1 (With Aker BP)
Lindberg, D. V., Rimstad, E., & Omre, H. (2015). Inversion of well logs into facies accounting for spatial dependencies and convolution effects. *Journal of Petroleum Science and Engineering*, *134*, 237-246. https://doi.org/10.1016/j.petrol.2015.09.027 (With Equinor)
Martinelli, G., Eidsvik, J., Hokstad, K., & Hauge, R. (2014). Strategies for petroleum exploration on the basis of Bayesian networks: A case study. *SPE Journal*, *19*(04), 564-575. https://doi.org/10.2118/159722-PA (With Equinor)
Skauvold, J., Eidsvik, J., & Theune, U. (2016). A parametric model for seismic wavelets—With estimation and uncertainty quantification. *Geophysical Journal International*, *205*(2), 796-809. https://doi.org/10.1093/gji/ggw029 (With Equinor)

NTNU-IMF 4

Institution: NTNU
Administrative unit: NTNU-IMF (Department of Mathematical Sciences)
Title of case study: Electronic voting
Period when the underpinning research was undertaken: 2012-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2012-2022
Period when the impact occurred: 2012-2023

1. Summary of the impact

Our work on the design and analysis of cryptographic voting systems was used as the basis for the cryptographic voting scheme used in the 2013 trial of internet voting in Norway. The mathematical analysis increased confidence in the technical security of the voting system. This system was the foundation for the current voting system being developed and deployed in Switzerland, as well as the voting system currently being sold by Scytl. The latter system was used for internet voting in the Church of Norway elections in 2023, where Gjøsteen helped run the election.

2. Underpinning research

The design of the 2013 system was done in 2012 and published in 2013. The main reference is the preprint Gjøsteen (2013), which describes the cryptographic voting scheme, defines what security means for the voting scheme and proves that the scheme achieves the desired security under reasonable cryptographic assumptions and idealisations.

The 2013 scheme was a development of an earlier scheme by Gjøsteen. The key advantages were critical performance improvements making it possible to use the voting system without Java applets, which at the time were a significant source of security vulnerabilities. The security analysis in the 2013 scheme was also a significant improvement over the earlier scheme's analysis, significantly increasing confidence in the scheme.

The key technical novelty in this class of schemes was a better method for computing so-called return codes, which are used by the voter to ensure that their ballot has been received correctly by the system, without compromising the privacy of the ballot. The technique is based on the homomorphic property of the ElGamal cryptosystem, as well as the pseudo-random properties of exponentiation in certain cyclic groups when the base is carefully chosen.

At the time, providing security proofs for the cryptographic voting schemes was also a novelty for deployed schemes, though this has since changed.

One huge question was if the return code mechanism really did help secure the election, which crucially hinges on the behaviour of voters - humans. Gjøsteen's chapter in Hao and Ryan (2017) presents some positive anecdotal evidence. Gjøsteen and Lund (2016) evaluated the return code mechanism in carefully designed laboratory, and found evidence that the mechanism would not protect every individual voter, but would provide some protection for the overall election.

Like most cryptographic systems, deployed cryptographic voting schemes are not quantum-safe. Continued use of electronic voting is contingent on the development of quantum-safe alternatives. Work like Aranha et al. (2023) are key steps towards practical quantum-safe cryptographic voting systems. Without this work, expending resources to deploy electronic voting today would be a highly uncertain proposition.

The key researcher was professor Kristian Gjøsteen (associate professor until 2014). The two PhD students Anders Smedstuen Lund (graduated 2015) and Tjerand Silde (graduated 2022) played key roles for parts of the research.

3. References to the research

Diego F. Aranha, Carsten Baum, Kristian Gjøsteen, Tjerand Silde: Verifiable Mix-Nets and Distributed Decryption for Voting from Lattice-Based Assumptions. CCS 2023: 1467-1481. https://doi.org/10.1145/3576915.3616683

Gjøsteen, K., Lund, A.S. An experiment on the security of the Norwegian electronic voting protocol. Ann. Telecommun. 71, 299–307 (2016). https://doi.org/10.1007/s12243-016-0509-8

Kristian Gjøsteen: The Norwegian Internet Voting Protocol. IACR Cryptol. ePrint Arch. 2013: 473 (2013). http://eprint.iacr.org/2013/473

Hao, F., & Ryan, P.Y.A. (Eds.). (2016). Real-World Electronic Voting: Design, Analysis and Deployment (1st ed.). Auerbach Publications. https://doi.org/10.1201/9781315371290 and freely available from https://realworldevoting.com

4. Details of the impact

The key impact is of course the use of electronic voting in certain districts during the parliamentary elections in 2013, and while other designs were available, their performance was lower and the evidence for their security was significantly weaker.

It is extremely difficult to document the impact of the improved security analysis, but we mention one piece of evidence: the Minister for local goverment stated that "mathematical proof can be given that the vote remains unchanged from the time it leaves the voter until it is counted" in a debate in the Norwegian parliament, referencing our analysis of the earlier scheme. Again, this is only incidental, but we claim it is suggestive.

While the new government elected in 2013 declined to continue with internet voting (based on a perceived risk of coercion), the experiments made electronic voting possible for several local referendums that were held in the following decade, where internet voting almost certainly increased participation, in particular during the Covid pandemic (e.g. the all-digital referendum in Innlandet in 2022). Partially based on the analysis from Gjøsteen and Lund (2016), these did not use the return code mechanism, greatly simplifying the deployment of the voting systems.

The Church of Norway elections in 2023 used internet voting to simplify access to the election. Gjøsteen was a member of the internet voting board.

5. Sources to corroborate the impact

Unfortunately, most of the corroborating sources are only available in Norwegian:

Debate in Stortinget (parliament)

The evaluation of the 2013 election

The 2022 referendum in the county Innlanded (all-digital voting)

The Church of Norway election in 2023

NTNU-IMF 5

Institution: NTNU
Administrative unit: NTNU-IMF (Department of Mathematical Sciences)
Title of case study: Modelling large-scale biodiversity data.
Period when the underpinning research was undertaken: 2013-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2016-2022
Period when the impact occurred: from 2021

1. Summary of the impact

Models for the distributions of species have been developed, that can account for huge biases in the way the data were collected. These have been (and continue to be) used to assess the aspects of the current state of biodiversity in Norway and other countries, e.g. deer distributions in the UK and Ireland.

2. Underpinning research

A problem with biodiversity data is that it has biases: a lot of the data is collected opportunistically, so tends to be collected in areas easily accessible to large numbers of people. Better designed surveys also exist, but tend to be much smaller. A way to combine the data to make use of the best of each data set, and overcome the worst of each data set, would be a great advance. We (and others) have developed these methods, starting in 2014. One reason for Prof. O'Hara moving to NTNU in 2016 was to work more closely with the developers of INLA, which is used "under the hood" in the models.

At NTNU the methods have been implemented and released as usable software. The models have been improved, in particular a framework for treating different types of sampling bias has been developed, and we found that the spatial bias in opportunistic data can be efficiently corrected by using a spatial field, without needing covariates (but we do need survey data).

We currently have flexible models and software to model distributions of species, and experience in applying them to different data.

The research was lead by Prof. O'Hara, who joined NTNU in December 2016. Other work was carried out by a post-doc, Dr. Emily Simmonds (2018-2021), and students Kwaku Adjei (2019-2023), and Philip Mostert (from 2021).

The development has been one in the context of other projects (e.g. https://citizenscience.no/), and with partners including NINA and Artsdatabanken in Norway, and the Centre for Ecology and Hydrology and the University of York in the UK.

3. References to the research

Adjei, K.P., O'Hara, R.B., Koch, W., Finstad, A.G. (2023) Modelling heterogeneity in the classification process in multi-species distribution models can improve predictive performance arXiv. DOI: 10.48550/arXiv.2305.01989

Mostert, P.S., O'Hara, R.B., (2023) PointedSDMs: An R package to help facilitate the construction of integrated species distribution models. Methods in Ecology and Evolution 14: 1200-1207. DOI: 10.1111/2041-210X.14091

Isaac, N.J.B., Jarzyna, M.A., Keil, P., Dambly, L.I., Boersch-Supan, P.H., Browning, E., Freeman, S.N., Golding, N., Guillera-Arroita, G., Henrys, P.A., Jarvis, S., Lahoz-Monfort, J. (2020) Data Integration

for Large-Scale Models of Species Distributions. Trends in Ecology & Evolution 38: 56-67. DOI: 10.1016/j.tree.2019.08.006
Simmonds, E.G., Jarvis, S.G., Henrys, P.A., Isaac, N.J.B. and O'Hara, R.B. (2020), Is more data always better? A simulation study of benefits and limitations of integrated distribution models. Ecography. DOI: 10.1111/ecog.05146

4. Details of the impact

The methods and software have already been used to inform conservation decisions:
- they have been used to model deer distributions in Ireland
- they have also been used to model deer distributions in the UK
- in Norway they are being used to model hotspots of biodiversity, as part of a project funded by the Norwegian Environment Agency.

In all of these cases the scientific work has involved using our models and software to predict the distributions of species, and then applying that knowledge. For example, mapping hotspots of biodiversity can be used to prioritise conservation effort, and to highlight areas where land use changes could have large impacts.

The main impacts have thus been to support conservation and biodiversity planning by providing high quality information on the distribution of species, and how they are affected by the environment. Going forward, this will be a key underpinning of projects in the Gjærevoll Centre at NTNU, continuing the impacts of this work.

5. Sources to corroborate the impact

Finstad A.G., Herfindal I., Perrin S., O'Hara R.B., Chipperfield J., Töpper J.P. (2023). Modellering av heildekkande utbreiingskart for arter: Bakgrunn, konsept og arbeidsflyt. NTNU Gjærevollsenteret, rapport 1/2023, Norges Teknisk Naturvitenskapelige Universitet

Cowie, CE, Harrison, LJ, Wiethase, J, Touza, J, Critchlow, R., Thomas, E., Fagan, S., Mostert, P.S., Ward, A.I., Beale, C., Hill, J., White, P.C.L. (2023) Natural capital and carbon impacts of deer in England. Report for the Forestry Commission, UK.

OsloMet, TKD, Department of Built Environment, Impact Case 1

Institution: Oslo Metropolitan University, Faculty of Technology, Art and Design (TKD)
Administrative unit: Department of Built Environment (BE)
Title of case study: HYPERION Project: "Development of a Decision Support System for Improved Resilience & Sustainable Reconstruction of Historic Areas to cope with Climate Change & Extreme Events based on Novel Sensors and Modelling Tools: The HYPERION Approach"
Period when the underpinning research was undertaken: June 1st, 2019 to May 31st, 2023 (with the 6-months extension of the project)
Period when staff involved in the underpinning research were employed by the submitting institution: June 1st, 2019 to May 31st, 2023
Period when the impact occurred: June 1st, 2019 to May 31st, 2023

1. Summary of the impact (indicative maximum 100 words)

This section should briefly state what specific impact is being described in the case study.

HYPERION constituted an interdisciplinary research project engaging 19 entities across eight European countries. Participants from Norway included OsloMet and Vestfold County. The project spanned from 2019 to 2023 and featured four case studies examining climate change impacts: Spain (Granada), Italy (Venice), Greece (Rhodes), Norway (Tønsberg).

The first impact manifested as an enhanced resilience and reduced vulnerability of historic areas concerning climate change and various natural hazards, considering their synergistic effects. A subsequent impact involved the improved reconstruction, along with economic and social recovery, of historic areas facilitated by local authorities and communities using new knowledge and tools.

2. Underpinning research (indicative maximum 500 words)

In the realm of cultural heritage preservation, the Hyperion project emerges as a beacon of innovation and climate change resilience. Tasked with addressing the profound challenge of deteriorating Cultural Heritage (CH) sites, our interdisciplinary team embarked on a comprehensive exploration encompassing:

- climate loads and natural hazards,
- building technologies and monitoring,
- structural responses and building physics phenomena,
- preventive measures and restoration strategies,
- climate change resilience, and
- adaptation methodologies.

At the heart of our endeavor lies a critical realization; the omnipresent threat of climate change looms large over these historical treasures. The Hyperion team introduced a groundbreaking Hygro-Thermal (HT) simulation tool to address this challenge. This tool, intricately designed to consider the coupled Heat, Air, and Moisture (HAM) transport phenomena, provides a nuanced understanding of climate change's impact on CH sites.

The preservation narrative seamlessly transitions into structural and geotechnical (SG) safety risks, where innovative simulators and sensors fueled by drone monitoring data play a pivotal role. This data-driven approach enables proactive risk mitigation, ensuring the conservation of historical structures and the safety of those interacting with them.

Environmental and Material Monitoring, the next chapter in our tale, introduces cutting-edge technologies such as Computer Vision (CV) and Machine Learning (ML) algorithms. These digital tools harness gathered data to facilitate precise CH site inspections. This amalgamation of technology and conservation science allows for accurately identifying states and diagnosing damages.

The project comprised a total of 10 Work Packages. OsloMet assumed the leadership role for WP5, designated "Multi-Hazards Modelling, Vulnerability & Impact Assessment of the historic areas". Additionally, it contributed to other Work Packages, particularly playing a significant role in WP4, titled "Characterisation of the Building Materials and Identification of the Deterioration Patterns". Within WP5, detailed models and simplified surrogate models were developed to facilitate rapid post-event reassessment, specifically in non-real-time (n-RT) scenarios. These models were integrated into software flow-state vulnerability modules, establishing a framework that facilitated the flow of information from hazard assessment to component state and overall system risk/resilience. The work also involved coding the core of the HRAP engine, determining impacts, risks, and resilience, and evaluating mitigation tools.

WP5 drew inputs from WP2 ("Communities of Practices (CoP), End-User Requirements and Platform Design") and WP3 ("Atmospheric Forcing Modelling, Weather Now/Forecasting and Data Processing") and maintained interactions with WP4 ("Characterisation of the Building Materials and Identification of the Deterioration Patterns") and WP6 ("Earth Observation, Sensor Data and Geospatial Services for increased resilience of the CH areas") within the project. The outcomes of WP5 played a crucial role in supporting the objectives of WP7 ("Implementation of the HRAP, the Communities' Engagement Tool, the DF tool and the DSS") and WP8 ("On-site Integration and Demonstration Activities").

Names of key researchers:

- Mahdi Kioumarsi, Associate Professor, Department of Built Environment, OsloMet.
- Dimitrios Kraniotis, Associate Professor, Department of Built Environment, OsloMet.
- Vagelis Plevris, Professor, Department of Built Environment, OsloMet.
- Amirhosein Shabani, PhD candidate, supervisors Mahdi Kioumarsi and Vagelis Plevris.
- Petros Choidis, PhD candidate, supervisors: Dimitrios Kraniotis (09/2019 - 02/2023) and Arnab Chaudhuri.
- Giulia Grottesi, researcher, supervisor: Dimitrios Kraniotis.

3. References to the research (indicative maximum of six references)

1. Shabani, A.*; Kioumarsi, M.; Zucconi, M., 2021**. State of the art of simplified analytical methods for seismic vulnerability assessment of unreinforced masonry buildings**. *Engineering Structures,* 239, p.112280. DOI: 10.1016/j.engstruct.2021.112280
2. Choidis, P.; Kraniotis, D.; Lehtonen, I.; Hellum, B. A Modelling Approach for the Assessment of Climate Change Impact on the Fungal Colonization of Historic Timber Structures. *Forests* **2021**, *12*, 819. https://doi.org/10.3390/f12070819
3. Shabani, A.* and Kioumarsi, M., 2022. A novel macroelement for seismic analysis of unreinforced masonry buildings based on MVLEM in OpenSees. *Journal of Building Engineering*, 49, p.104019. DOI: 10.1016/j.jobe.2022.104019
4. Shabani, A.* and Kioumarsi, M., 2022. Hyperomet: An OpenSees interface for nonlinear analysis of unreinforced masonry buildings. *SoftwareX,* 20, p.101230. DOI: 10.1016/j.softx.2022.101230

5. Grottesi, G.; Coelho, G.B.A.; Kraniotis, D. Heat and Moisture Induced Stress and Strain in Wooden Artefacts and Elements in Heritage Buildings: A Review. *Appl. Sci.* **2023**, *13*, 7251. https://doi.org/10.3390/app13127251

6. Shabani, A.* and Kioumarsi, M., 2023. Seismic assessment and strengthening of a historical masonry bridge considering soil-structure interaction. *Engineering Structures,* 293, p.116589. DOI: 10.1016/j.engstruct.2023.116589

4. Details of the impact (indicative maximum 750 words)

The HYPERION project, a collaborative research initiative involving Department of Built Environment at Oslo Metropolitan University and several other European institutions, has made a significant contribution to preserving and enhancing the resilience of CH sites against natural and man-made hazards. The research conducted within this project focused on the development of advanced hazard modelling tools and SG tool interfaces. These innovative tools have facilitated the rapid assessment of potential hazards and their impacts on CH sites, enabling more timely and effective responses.

Beyond the technical development of these tools, the research conducted by Department of Built Environment within the HYPERION project has made a distinct and material contribution to several areas of impact.

The pilot cases in Tønsberg, Norway; Rhodes, Greece; Granada, Spain; and Venice, Italy were successfully executed as part of the project. By collaborating closely with these cities, the project team developed comprehensive action plans aimed at safeguarding their cultural heritage. These plans encompass various aspects such as maintenance strategies, conservation measures, and other relevant initiatives. Through tailored approaches, each city was equipped with practical frameworks to ensure the preservation and sustainable management of its cultural heritage assets. This initiative greatly enhances the ability to protect and preserve CH sites, providing municipalities with invaluable tools and models to understand and mitigate potential risks effectively. By raising awareness among policymakers about the importance of resilience in CH sites, this research has influenced policy decisions related to heritage preservation, further contributing to the safeguarding of communities' cultural and historical heritage.

Another significant area of impact is the contribution made to scientific knowledge in the field of hazard modelling and vulnerability assessment. The research outputs from the HYPERION project have been widely recognized for their novelty and applicability. They have also led to an increase in new research endeavours in this field.

The research has also made a tremendous contribution to stakeholders' abilities involved in CH site management. The tools and models developed as a part of the HYPERION project provide a robust and comprehensive means for hazard assessment and mitigation. This has improved the decision-making abilities of these stakeholders and has led to more effective management of CH sites.

The beneficiaries of this research are diverse and widespread. Local and international communities, for whom CH sites hold cultural and historical significance, have benefited significantly from the improved resilience of these sites. The scientific community has gained from the innovative research outputs and the advancements in the field of hazard modelling and vulnerability assessment. Policymakers and stakeholders involved in CH site preservation have gained access to advanced tools and models for hazard assessment and mitigation, improving their ability to make informed decisions. In particular, the open-access Holistic Resilience Assessment Platform (HRAP) that HYPERION has developed links weather and climate data with hygrothermal, structural and geotechnical responses, and furthermore computes the socioeconomic impact for individual buildings as well as for entire cities. HRAP is fed with live data, while the building physics, structural and geotechnical models run in the background in order to predict the impact.

While the research conducted by Oslo Metropolitan University was part of a larger collaborative effort, its specific contribution to developing the SG tool interfaces was instrumental to the project's success. The university played a significant role in the project's overall success, acknowledging the key contributions made by other institutions.

The impacts of this research have been occurring throughout the project's duration since 2019. They are expected to continue as the developed tools and models are further refined and applied to additional CH sites.

In addition to the academic and practical impacts mentioned above, the project has also seen a media impact. The improved resilience of CH sites against hazards, as a direct result of the research conducted under the HYPERION project, has been reflected in media interactions. Notable mentions include outlets like NRK P1 Radio and NRK1 TV.

Overall, the HYPERION project's research has had a significant and widespread impact on various stakeholders. It has improved the resilience of CH sites, advanced scientific knowledge, and provided valuable tools for policymakers and stakeholders involved in CH site management. The impact is a testament to the value that research can bring to society and the importance of preserving our cultural heritage.

5. Sources to corroborate the impact (indicative maximum of ten references)

1. Shabani, A.*, Kioumarsi, M., Zucconi, M., 2021. State of the art of simplified analytical methods for seismic vulnerability assessment of unreinforced masonry buildings. *Engineering Structures,* 239, p.112280. DOI: 10.1016/j.engstruct.2021.112280
2. Shabani, A., Hosamo, H., Plevris, V., & Kioumarsi, M., 2021. A Preliminary Structural Survey of Heritage Timber Log Houses in Tønsberg, Norway. In *12th International Conference on Structural Analysis of Historical Constructions (SAHC 2021). International Centre for Numerical Methods in Engineering*. Barcelona, Spain, 29-30 September and 1 October.
3. Choidis, P., Kraniotis, D., Lehtonen, I., Hellum, B., 2021. A Modelling Approach for the Assessment of Climate Change Impact on the Fungal Colonization of Historic Timber Structures. *Forests*, *12*, 819. https://doi.org/10.3390/f12070819
4. Shabani, A.* and Kioumarsi, M., 2022. A novel macroelement for seismic analysis of unreinforced masonry buildings based on MVLEM in OpenSees. *Journal of Building Engineering*, 49, p.104019. DOI: 10.1016/j.jobe.2022.104019
5. Shabani, A.* and Kioumarsi, M., 2022. Hyperomet: An OpenSees interface for nonlinear analysis of unreinforced masonry buildings. *SoftwareX,* 20, p.101230. DOI: 10.1016/j.softx.2022.101230
6. NRK P1 Radio, 2022. "HYPERION Project: Enhancing Historic Sites Resilience", Radiolangs NRK P1, March 2022. Available at: https://radio.nrk.no/serie/radiolangs-nrk-p1/sesong/202211/PLUV05023722#t=1h5m55s (from 1:05 to 1:10)
7. NRK1 TV, 2022. "Preserving Historical Sites: The HYPERION Approach", Nyhetsmorgen TV, April 2022. Available at: https://tv.nrk.no/serie/nyhetsmorgen-tv/202211/NNFA05112922#t=4206s (from 1:10 to 1:14)
8. Grottesi, G., Coelho, G.B.A., Kraniotis, D., 2023. Heat and Moisture Induced Stress and Strain in Wooden Artefacts and Elements in Heritage Buildings: A Review. *Appl. Sci.* 2023, *13*, 7251. https://doi.org/10.3390/app13127251
9. Shabani, A.* and Kioumarsi, M., 2023. Seismic assessment and strengthening of a historical masonry bridge considering soil-structure interaction. *Engineering Structures,* 293, p.116589. DOI: 10.1016/j.engstruct.2023.116589
10. Choidis, P., Coelho, G.B.A., Kraniotis, D., 2023. Assessment of frost damage risk in a historic masonry wall due to climate change. Advances in Geosciences, 58, p. 157-175. DOI = https://doi.org/10.5194/adgeo-58-157-2023

OsloMet, TKD, Department of Built Environment, Impact Case 2

Institution:	Oslo Metropolitan University (OsloMet), Faculty of Technology, Art and Design (TKD)
Administrative unit:	Department of Built Environment (BE)
Title of impact case:	Improved building operation and air quality of buildings with demand-controlled ventilation.
Period when the underpinning research was undertaken:	2009-2019 (two sequential research projects)
Period when staff involved in the underpinning research were employed by the submitting institution:	2009 onwards (during entire project period, still employed)
Period when the impact occurred:	2013 to 2022 exhibited a gradual growth of societal impacts. Permanent benefit after this.

Summary of the impact

Nationwide improvement in competence* on specifying, sizing, commissioning, and operation of demand-controlled ventilation in buildings. Tangible societal benefits include:

- Reduced capital costs due to more correct system design, component sizing and fitting, and significantly fewer faults in ventilation and building automation, on handover of new buildings.
- Reduced operational energy costs due to inferior commissioning and faults that appear during operation.
- Improved indoor air quality due to more reliable and accurate operation.

(* engineering consultancies, HVAC product manufacturers and suppliers, building contractors, property developers, facility managers, vocational and higher education establishments, research organizations.)

Underpinning research

The research was conducted in the frame of the two research projects listed below. Both projects were funded by the Research Council of Norway (RCN). SINTEF and OsloMet were main scientific partners, together with stakeholders from the building trade, and other research organizations:

- Project ***reDuCeVentilation*** [Link to website with detailed project results] (2009-2013). Research group participants Adjunct professor **Mads Mysen**, and Professor **Peter Schild**, and 2 **masters' students**.

  This project focused on developing and disseminating robust, demand-controlled ventilation solutions, particularly for educational buildings, to reduce energy usage and improve air quality. The key insights include the development of concepts for robust demand control, spreading knowledge about the potential in educational buildings, and creating calculation tools to document this potential in compliance with Norwegian building regulations. The impact of the research is significant in terms of resource optimization and functional ventilation systems, with a particular focus on schools, but applicable to all building types. The underpinning research produced practical guidelines, control procedures, and calculation tools to ensure the effective implementation and maintenance of these ventilation systems.
- Follow-on project ***BestVent*** [Link to website with details project results] (2016-2019). Research group participants Adjunct professor **Mads Mysen**, Professor **Peter Schild**, PostDoc **Aileen Yang**, and 6 **masters' students**.

This project aimed to further enhance knowledge and recommendations on appropriate air volumes and ventilation strategies for demand-controlled ventilation systems in schools and office buildings. The project focused on robust recommendations based on actual exposure risks, usage patterns, and optimal energy use, addressing inconsistencies in current regulations and the lack of updated professional grounding. The project's findings emphasize the importance of tailored ventilation strategies for indoor air quality and energy efficiency.

Staff

Names and positions of key researchers, all of whom are connected to the research group SustainaBuilt at OsloMet department of Built Environment:

- Adjunct professor **Mads Mysen**, employed at OsloMet since 2009 (the first part of the period as a PostDoc).
- Professor **Peter G. Schild**, employed at OsloMet since 2012 (the first year as a PostDoc). Part-time position at SINTEF.
- Postdoc **Aileen Yang**, employed at OsloMet 2017-2020. Since then employed at SINTEF.
- Furthermore, a number of **masters' students** have been engaged from the "Energy & Environment in Buildings" degree programme.

This overview shows the significance of postdoc positions in recruiting academic staff.

3. References to the original research (selection)

Names in bold are research group members and associated members, including masters' students:

- **Mads Mysen, Peter G. Schild**, Axel Cablé (2014) *"Demand-controlled ventilation – requirements and commissioning"*, SINTEF Academic Press, ISBN: 978-82-536-1414-4 URL: http://hdl.handle.net/11250/2373190
- **Mads Mysen, Peter G. Schild** (2014) *"Behovsstyrt ventilasjon, DCV – forutsetninger og utforming. Veileder for et energioptimalt og velfungerende anlegg"* [In Norwegian], SINTEF Academic Press, ISBN: 978-82-536-1372-7, URL: http://hdl.handle.net/11250/2372940
- Sverre B Holøs, **Aileen Yang, Merethe Lind**, Kari Thunshelle**, Peter Schild, Mads Mysen** (2018) «VOC emission rates in newly built and renovated buildings, and the influence of ventilation – a review and meta-analysis", *International Journal of Ventilation*, 18:3, p.153-166 https://doi.org/10.1080/14733315.2018.1435026
- **Mads Mysen**, Sverre Holøs, **Aileen Yang**, Kari Thunshelle, **Peter Schild** (2018) "What should the minimum ventilation rate be in a Demand-Controlled Ventilation strategy?", In: Johansson, D., Bagge, H., Wahlström, Å. (eds) *Cold Climate HVAC 2018. CCC 2018*. Springer Proceedings in Energy. Springer, Cham. https://doi.org/10.1007/978-3-030-00662-4_29
- Sverre B Holøs, **Aileen Yang**, Kari Thunshelle and **Mads Mysen** (2019) "Effect of ventilation on perceived air quality in 18 classrooms", *IOP Conf. Ser.: Mater. Sci. Eng*. 609:4, p.042038, https://doi.org/10.1088/1757-899X/609/4/042038
- **Aileen Yang**, Sverre B. Holøs, **Marie Opsahl Resvoll, Mads Mysen**, Øystein Fjellheim (2021) "Temperature-dependent ventilation rates might improve perceived air quality in a demand-controlled ventilation strategy", *Building and Environment*, Vol.205, https://doi.org/10.1016/j.buildenv.2021.108180

4. Details of the impact

Examples of dissemination activities and beneficiaries of both research projects:

- Both projects have detailed websites listing dissemination products. Both websites will be kept alive for the unforeseen future.
- In 2016, the project developed a commissioning protocol (by P.G.Schild) which is an integral tool for the below publications by both SINTEF and OsloBygg.

- In 2016, SINTEF published four new guides (by M. Mysen) on demand-controlled ventilation in its online subscription "Byggforskserien" series (https://www.byggforsk.no/). This series is a national knowledge library for the building sector, with more than 5000 subscriptions (and a larger number of individual users). It is used as standard reference documents in building projects, as documentation of compliance with the building regulations.
- In 2016, the project partner Oslo municipal enterprise *UndervisningsBygg* (now called *OsloBygg*) implemented its first technical requirements for demand control ventilation in Schools. This has since been implemented in a 2022 technical specification for all building categories. These specifications have led to a 90% reduction in problems at handover.
- SINTEF developed a Continued Professional Development (CPD) course on commissioning of demand-controlled ventilation systems, which now runs twice yearly since 2018. HVAC contractors, service technicians, and facility managers, attend these courses.
- Adjunct professor Mads Mysen toured the main cities in Norway, holding a shorter version of the above course, and during the pandemic, recorded a free digital online version of the course. These activities were conducted under the auspices of the Norwegian HVAC Energy and Environment Society (NEMITEK), who was in the reference groups of both projects.
- OsloMet has improved its research-based teaching in course MAEN4400 (Ventilation technology), and both projects engaged masters' students (thesis projects).

The following points list characteristics of both projects that we feel helped to underpin a successful impact:

- Research Council of Norway (RCN) funded 80% of the total costs, on the condition of 20% co-financing (financial, not "in kind") from industrial partners. The involvement of industry ensured that the research priorities were aligned with the needs of the building sector and industry. Partners also contributed in terms of industry knowledge, case study buildings, and media access.
- All partners were selected to be complementary, overseeing diverse segments of public and private sectors. All partners had a contributory role; funding industrial partners therefore supported the project in other ways than merely funding, such as technology access, application, and media dissemination. This is illustrated by the list or partners, below.

  The following kinds of partners were engaged (complete list is available on the aforementioned project websites): Public sector/authorities, Private property management, Manufacturers/suppliers, Service-providers, Building/technical contractors, Engineering consultancies, Professional bodies, Scientific partners.
- Communication with national partners was in Norwegian. We experience that language skills are an essential aspect of successful networking, engagement of stakeholders, and engagement of media nationally. Non- Norwegian speaking members of staff report that they experience that the language barrier significantly curtails their access to national networking opportunities.
- Both projects were professionally organized, with regular meetings of the "steering committee/board" consisting of funding partners. This ensured deeper engagement of stakeholders, and continuous review of the project priorities.
- The projects also engaged "reference groups" consisting of both stakeholders (especially authorities) and other research organizations, giving guidance. These were organized in the frame of annual review workshops. Also media (trade journals and professional bodies) were invited and kept informed.
- Both projects finished with closing seminars, which were open to all interested parties.
- Diverse dissemination activities continued after each project.

5. Sources to corroborate the impact (selection of media references)

- Link to 2015 trade journal article Mads Mysen, Peter Schild, Axel Cablé, John Woollett. "Commissioning for energy—optimal demand controlled ventilation". *REVHA Journal*, 52:2, p.20-24. URL: https://www.rehva.eu/fileadmin/REHVA_Journal/REHVA_Journal_2015/RJ_issue_2/P.20/20-24_RJ1502_WEB.pdf
- Link to commissioning protocol [available as PDF and XLSX file]
- Link to 2016 *municipal enterprise UndervisningsBygg's technical guide "Guide for demand contron ventilation"* [In Norwegian]. This document is a direct result of research project reDuceVentilation, in which SINTEF, OsloMet, and Undervisningsbygg (now OsloBygg) were partners.
- Link to 2022 municipal enterprise OsloBygg's technical specification *"Standard specifications – Technical and operations & maintenance requirements"* [In Norwegian]. Section §300 *"HVAC installations, general: Ventilation system"*, refers to new requirements and test procedures, and a test protocol listed below. This is a revised version of the above spec from 2016.
- Link to 2016 SINTEF guide *"552.326: Demand Controlled Ventilation (DCV). Commissioning and documentation of system function"* [In Norwegian, access required subscription]. This guide summarizes the recommendations from the research, including the new integrated function test.
- Link to *SINTEF "Course in commissioning of demand-controlled ventilation"* [In Norwegian]. This is a CPD (Continued Professional Development) course for HVAC contractors and facility managers. The course is run twice yearly. It is a direct result of the research, and project participants act as teachers.
- Link to 2020 news article *«School building authorities in Oslo got help from BestVent-project, significantly increased the number of approved buildings on commissioning»* [in Norwegian], published by Norwegian HVAC Energy and Environment Society (NEMITEK). In the news article, a representative for the Oslo School Authority states that the fraction of schools that passed the first handover approval checks increased from 10% to 90% over a period of 5 years as a result of this research.
- Link to 2020 news article *"Success-Mysen goes digital"* [In Norwegian], published by Norwegian HVAC Energy and Environment Society (NEMITEK). The ingress is *"Mads Mysen has received applause nationwide with the NEMITEK course "Well-functioning Demand-Controlled Ventilation". Now that it is being launched in a digital version, far more people will have the opportunity to get updated"*. This free mini on-line course covers highlights from the SINTEF course. Mads Mysen is Adjunct Professor at OsloMet.

OsloMet, TKD, Department of Computer Science, Impact Case 2 Quantum Computing

Institution: Oslo Metropolitan University – Faculty for Technology, Art and Design
Administrative unit: Department of Computer Science
Title of case study: Quantum Computing
Period when the underpinning research was undertaken: 2019 - 2024
Period when staff involved in the underpinning research were employed by the submitting institution: 2019 - 2024
Period when the impact occurred: 2021-2024

1. Summary of the impact (indicative maximum 100 words)

Quantum computing has the potential to change the world dramatically, and Norway risks failing to keep up with the rest of the world. OsloMet has had a leading role in Norway when it comes to advocating the importance of quantum computing in public media. We brought the first two quantum computers to Norway in a large event, we have participated in numerous podcasts and interviews, we have co-published a position paper, we educate students in quantum technology, we organize winter schools on the topic, and we will (fall 2024) have a continued education course on quantum technology for non-experts. Our students have already made societal impact through their work at Ruter – Oslos public transportation company – where quantum computing has been used in planning ticket inspections.

2. Underpinning research (indicative maximum 500 words)

Quantum computing as a research field is not new, but OsloMet started working more actively with this field in 2019 with the hiring of a position within the topic. The activity has grown dramatically since then and is still increasing.

The research is committed in several research projects including NordSTAR (https://www.oslomet.no/en/nordstar), the OsloMet Quantum Hub (https://www.oslomet.no/en/about/tkd/it/quantum-hub) and DQUANT (https://quantera.eu/dquant/).

The key researchers involved at OsloMet are Sergiy Denysov (Professor of theoretical physics), Sølve Selstø (Professor of physics), and Pedro Lind (Professor of scientific computing), and the team involves PhD students on various topics within quantum computing (Bendik Dalen, Kristian Wold, and Heine Aabø). In addition, we have educated 10-20 students every year since 2020 in quantum technologies (https://student.oslomet.no/studier/-/studieinfo/emne/ACIT4321/2020/H%C3%98ST). Several of our students have already been hired by Ruter – Oslos public transport company – to commit applied research into how quantum computing can benefit optimization (and other) problems in public transportation. It has already been used for ticket inspection route planning with better results than traditional approaches.

3. References to the research (indicative maximum of six references)

This impact is mainly due to the combined effort in multiple channels. The references to "research" are therefore here reported as some of the channels that comprise this impact case.

- QCNorway Contributions Towards a Norwegian Quantum Computing Strategy Are Magnus Bruaset, Shaukat Ali, André Brodtkorb, Gunnar Bøe, Sergiy Denysov, Hans Eide and Sølve Selstø

https://static1.squarespace.com/static/63285106209e4d17686f60f8/t/6480f3d9d3321876b65a19ff/1686172656059/2023-06-08+QCNorway+final.pdf

- Quantum Computing and AI: Why should we care? NORA Webinar https://www.nora.ai/nora-webinars/07012022quantum-computing.mp4?vrtx=view-as-webpage
- ERCIM News 128 (January 2022) Special theme: Quantum Computing Guest editors: Shaukat Ali (SIMULA) and Sølve Selstø (Oslo Metropolitan University) https://ercim-news.ercim.eu/en128/
- Norway's first ever quantum computer, Podcast in Viten og Snakkis. https://vitenogsnakkis.oslomet.no/2021/12/14/norways-first-ever-quantum-computer/
- Quantum computing for ticket inspection in public transport in Oslo "Maryam helps a public transport company to get ahead of technological development" https://www.oslomet.no/en/study/student-stories/maryam-helps-public-transport-company-to-get-ahead-of-technological-development
- Winter school on quantum computing: "Quantum jumps at Holmenkollen" https://uni.oslomet.no/quantum/2023/11/16/quantum-leaps-at-holmenkollen/

4. Details of the impact (indicative maximum 750 words)

The push towards quantum computing and quantum technologies has been substantial from OsloMet, with a contribution on everything from basic research to dissemination to the general public. We have three PhD students involved in the research, a master course with 20 annual students (unique in Norway - https://student.oslomet.no/studier/-/studieinfo/emne/ACIT4321/2021/H%C3%98ST), and a newly established course in the quantum world for non-experts (https://www.oslomet.no/studier/tkd/evu-tkd/introduksjon-kvanteverda)

In November 2021, we had a large event with the launch of the first two quantum computers in Norway, see https://film.oslomet.no/when-norway-went-quantum and https://www.youtube.com/watch?v=ijG3-AKbvII&t=822s. The event was visited by politicians, academia, public and private sector, and was written about in several computer science media.

Together with Simula, Sigma2, and SINTEF, we co-organized QCNorway (https://www.qcnorway.no/) in November 2022, which culminated with the position paper "Contributions Towards a Norwegian Quantum Computing Strategy" (available on aforementioned webpage). This position paper is a start to the discussion on how Norway should approach the scientific field of Quantum Computing, which has gained major tracktion internationally over the last five years.

The overall activity within quantum computing outreach at OsloMet is high, and a list of activities can be seen on https://uni.oslomet.no/quantum/selected-media-pieces/

5. Sources to corroborate the impact (indicative maximum of ten references)
Most of the material is available on online sources, but it is also possible to directly contact e.g.,

- Ruter AS, and
- Simula Research Laboratory

OsloMet, TKD, Department of Computer Science, Impact Case 1 ReproAI

Institution: Oslo Metropolitan University – Faculty for Technology, Art and Design
Administrative unit: Department of Computer Science
Title of case study: Artificial intelligence - a novel tool in assisted reproduction technology (ReproAI)
Period when the underpinning research was undertaken: 2018 - 2024
Period when staff involved in the underpinning research were employed by the submitting institution: 2018 - 2024
Period when the impact occurred: 2020 – 2024

1. Summary of the impact (indicative maximum 100 words)

Development of software and datasets that improves assisted reproduction technology (ART). Data from these image analyses will be coupled to reproductive outcomes.
The project aim has been to improve the methods for selecting sperm and embryos and thus increase the chance of pregnancy and ultimately a live birth, to elucidate if specific features in the development of the embryo increase the probability for treatment success.

Another impact in longer term perspective may be to a reduce the number of treatment cycles and to lower cost per treatment for those in need of assisted fertilization.

2. Underpinning research (indicative maximum 500 words)

The main body of the impact was a result of the research project ReproAI funded by The Research Council of Norway.

Artificial intelligence (AI) methods are especially suitable to obtain information from images and are in this case used as an important tool in medical treatment. In this project, AI methods were developed to analyse videos of embryo development, in order to develop strategies for making the selection of embryo and spermatozoa based on more objective criteria.

Deep learning models can characterize cell division and different stages of the embryo development. We have also developed neural networks which by analysing videos can categorize the spermatozoa according to their motility. Videos of spermatozoa, prior to selection for injection into the oocyte by the ICSI method (intracytoplasmic sperm injection), are presently being analysed and will thereafter be related to reproductive outcomes. Both the spermatozoa and the ICSI procedure are evaluated. The results will be used to make a tool for fertility clinics to assist in clinical decisions.

In traditional ART, embryologists use different grading schemes to evaluate the quality of different embryos and semen samples. However, the schemes can be both tedious and time consuming. In ReproAI, data driven techniques were developed to make the grading more efficient and less subjective. The research was conducted between 2018 and with planned end data April 2024.

The research project is an interdisciplinary collaboration between researchers from the Department of Life Sciences and Health, OsloMet (Trine B. Haugen and others), and the Department of Computer Science at OsloMet (Akriti Sharma and Hugo L. Hammer), Simula Metropolitan Centre for Digital Engineering - SimulaMET (Micheal Riegler and others), and the fertility clinic Volvat Spiren and Fertilitetssenteret (Mette Stenersen).

The main part of the embryo analysis was conducted by PhD candidate Akriti Sharma with main supervisor Hugo L. Hammer. Hugo L Hammer also contributed to the semen analysis that was mainly performed by SimulaMet.

3. References to the research (indicative maximum of six references)

Hicks, S. A., Andersen, J. M., Witczak, O., Thambawita, V., Halvorsen, P., Hammer, H. L., ... & Riegler, M. A. (2019). Machine learning-based analysis of sperm videos and participant data for male fertility prediction. *Scientific reports*, *9*(1), 16770.

Haugen, T. B., Hicks, S. A., Andersen, J. M., Witczak, O., Hammer, H. L., Borgli, R., ... & Riegler, M. (2019, June). Visem: A multimodal video dataset of human spermatozoa. In *Proceedings of the 10th ACM Multimedia Systems Conference* (pp. 261-266).

Riegler, M. A., Stensen, M. H., Witczak, O., Andersen, J. M., Hicks, S. A., Hammer, H. L., ... & Haugen, T. B. (2021). Artificial intelligence in the fertility clinic: status, pitfalls and possibilities. *Human Reproduction*, *36*(9), 2429-2442.

Sharma, A., Stensen, M. H., Delbarre, E., Haugen, T. B., & Hammer, H. L. (2022, June). Explainable Artificial Intelligence for Human Embryo Cell Cleavage Stages Analysis. In *Proceedings of the 3rd ACM Workshop on Intelligent Cross-Data Analysis and Retrieval* (pp. 1-8).

Sharma, A., Ansari, A. Z., Kakulavarapu, R., Stensen, M. H., Riegler, M. A., & Hammer, H. L. (2023). Predicting Cell Cleavage Timings from Time-Lapse Videos of Human Embryos. *Big Data and Cognitive Computing*, *7*(2), 91.

Sharma, A., Kakulavarapu, R., Thambawita, V., Siddiqui, M., Delbarre, E., Riegler, M., ... & Stensen, M. (2022, July). Automating tracking of cell division for human embryo development in time lapse videos. In *HUMAN REPRODUCTION* (Vol. 37, pp. I305-I306). GREAT CLARENDON ST, OXFORD OX2 6DP, ENGLAND: OXFORD UNIV PRESS.

4. Details of the impact (indicative maximum 750 words)

The research was conducted in close collaboration with the fertility clinic Volvat Spiren providing them experience in how data driven methods can be used to improve ART.

The dataset VISEM (https://datasets.simula.no/visem/) was developed and can help other clinics to improve the analysis of semen samples. The associated dataset paper has many citations (44 per Jan. 2024).

The VISEM “A Multimodal Video Dataset of Human Spermatozoa” is a dataset that is novel in two ways. Firstly, it is a multi-modal dataset containing different data sources such as videos, biological analysis data, and participant data. Secondly, it is the first dataset of that kind in the field of human reproduction. It consists of anonymized data from 85 different participants. We hope this dataset will inspire people to apply their knowledge in this important field, generate shareable results in the domain, and ultimately improve human infertility investigation and treatment.

Sperm-related data faces the same problems as other clinical datasets. First of all, it is often difficult to share data due to legal requirements. Secondly, the knowledge about what the data contains, and which are interesting medical research questions are often hard to find for researchers not familiar with the field. Finally, datasets are often also small compared to what would be effective for a proper analysis and evaluation of the results. We try to tackle the above-

mentioned challenges by providing a clinical dataset in an open and explained way to experts not familiar with the medical field. The goal is to encourage these researchers to explore a new and exciting medical domain and contribute to the society with their research. In addition, we encourage comparable and open research also in the medical field where data access is usually difficult and often restricted to a limited number of researchers. To the best of our knowledge, the dataset contains more samples and far more attributes per participant than any sperm dataset openly available today. The dataset opens for a wide range of new and interesting analyses, and a proper and fair comparison between different methods, both from a medical and a multimedia perspective.

5. Sources to corroborate the impact (indicative maximum of ten references)

VISEM dataset https://datasets.simula.no/visem/

https://www.oslomet.no/en/research/research-projects/ai-assisted-reproduction

OsloMet- Fak TKD- Dep. Mechanical, Electrical and Chemical Engineering – Impact Case 1

Institution: Oslo Metropolitan University - Technology Art and Design
Administrative unit: Department of Mechanical, Electrical and Chemical engineering
Title of case study: ADEPT impact case
Period when the underpinning research was undertaken: 2015 (start of ADEPT) – 2024
Period when staff involved in the underpinning research were employed by the submitting institution: 2015 - 2024
Period when the impact occurred: 2021 - 2024

1. Summary of the impact

The group's impacts societal health via technological research. The work spans both diagnostic and preventive healthcare, employing state-of-the-art technology to predict and diagnose neural circuit disorders in brain, while also promoting preventive measures that are mostly related to movement and body mechanics. The generated knowledge is applied to develop future technologies, advancing effectiveness and efficiency of electronic circuits. This innovation loop allows ADEPT research group to contribute to Intelligent health initiatives, creating a robust system that contribute to not only better health, but also educating the future generation in the local society. The group's forward-thinking approach ensures the promotion of health technology, benefitting both individuals and society at large.

2. Underpinning research

The ADEPT Research Group has developed a unique and innovative research approach that is cyclical in nature. Each project feeds into the next, creating a continuous loop of learning, application, and innovation. This process begins with a focus on initial research, specifically on brain Connectome. By using advanced brain modalities such as functional near-infrared spectroscopy (fNIRS) and electroencephalography (EEG), the group aims to map brain activities to predict and diagnose disorders of the brain's neural circuit.

The underlying belief is that incorrect sensory feedback leads to improper motor activation. This inefficient use of energy results in chronic pain and discomfort. By studying the brain's Connectome, researchers hope to understand these discrepancies and develop methods to correct them. The findings from this phase of research are invaluable, providing a foundation upon which to build preventive strategies.

The ability to anticipate and manage health issues proactively is a significant leap forward in healthcare. However, achieving this knowledge is not a solitary activity. It requires cross-disciplinary collaboration across several different fields of expertise. ADEPT has been able to initiate a collective collaborative unit, connecting three units within the Department of MEC: Mechanical, Electronics, and Chemical and Biotechnology.

The mechanical unit consisting of several colleagues (Profs. Fallah, Borrajo, Flåtten), are responsible for the biomechanical analysis, while the electronics unit consisting of several colleagues including (Profs. Mirtaheri, Korostynska, Khan, Muhtaroglu) handles all instrumentation. The chemical and biotechnology unit consisting of colleagues (Profs. Berge, Rønning, Lobert), on the other hand, undertakes the analysis of chemical and metabolomics. This cross-communication and collaboration allow ADEPT to fully utilize the strengths of each department, leading to more comprehensive and impactful research findings. ADEPT has also

connections across the faculty to achieve its goal in disciplines as psychology (Prof. Jonassen), Brain activities in Children (Prof. Papatzikis), medicine and its influence on brain connectome (Prof. Gazerani).

ADEPT is not limited to research alone. The group actively involves itself in innovative projects that can directly benefit the health sector. These projects range from the development of new technologies to the implementation of novel healthcare strategies. The group's work is not only contributing to the advancement of health technology but also shaping the future of healthcare.

Furthermore, ADEPT's work significantly contributes to educational programs. The research group offers a multitude of projects to students at all levels - Bachelors, Masters, and Ph.D. This involvement provides students with invaluable hands-on experience, exposing them to the realities and challenges of conducting research in the field of health technology.

3. References to the research

1. Single-leg stance on a challenging surface can enhance cortical activation in the right hemisphere – A case study/Heliyon/2023/ https://doi.org/10.1016/j.heliyon.2023.e13628 Interactions of human balance with neural codes
2. Brain Connectivity Analysis in Distinct Footwear Conditions during Infinity Walk Using fNIRS /Sensors/2023/ https://doi.org/10.3390/s23094422 Interactions of human balance with neural codes
3. The role of human experience when making sense of brain monitoring: an interdisciplinary case study to assess wearable, non-invasive, brain-monitoring devices for rehabilitation/Journal of Responsible innovation/2023/ https://doi.org/10.1080/23299460.2023.2175476

4. Details of the impact

Musculoskeletal disorders affect many working people and contribute to high levels of sickness absence and many people with disabilities. Only 1.2 million Norwegians contacted their GP for treatment of musculoskeletal disorders in 2015. Foot interaction with any shoe-wear relates to the sensory-motoric area of the brain to form a network that enables us to move and walk. Many back and neck pains are associated with neural circuit network disorders, and understanding the neural codes will enhance the existing treatment and rehabilitation strategies.

A Norwegian company (Gaitline AS) designs shoes specifically to stimulate sensory-motor feedback and adjust the foot-ground interactions in light of body segmental interconnections. The ADEPT group has established partnerships with Gaitline AS that has already made MMI research data based on lived experiences of individuals with different walking problems and musculoskleton issues that can be significantly improved by wearing their shoes (1-3). This engagement has helped the group prioritize research that addresses the most pressing concerns of potential problems. The applications may have vast direction involving sports athletes of different ages (ref. 4-5) in addition to average people as students.

The group has also collaborated with healthcare providers to gain insights into clinical practice, the challenges of diagnosing and treating neurological disorders, and the potential impact of new technologies. This collaboration has helped the group ensure that their research findings are translatable into clinical practice and improve patient outcomes. The collaboration impacts health in general and promotes health and disease prevention at the societal level. It is also promoting

technologies that can 1) promote health through partners such as Gaitline 2) apply the biological understanding in brain-inspired technologies to apply AI solutions.

5. Sources to corroborate the impact (indicative maximum of ten references)

1. A Viaplay documentary Aamodt Kilde part 3 (Jakten på hundredelene) /2023/https://viaplay.no/serier/aamodt-kilde
   The research impact on athletes performance.

2. Evaluating Cortical Activity and Balance Performance in Alpine Skiers Using Single-Leg Stance and Modified Hop Balance Test/2023/TechAxiv/ https://www.techrxiv.org/doi/full/10.36227/techrxiv.24188673.v2
   The research impact on athletes performance and understanding the balance related neural codes.

OsloMet- Fak TKD- Dep. Mechanical, Electrical and Chemical Engineering – Impact Case 2

Institution: Oslo Metropolitan University - Technology Art and Design
Administrative unit: Mechanical, Electrical and Chemical Engineering
Title of case study: Simulator knowledge transfer from petroleum to water industry
Period when the underpinning research was undertaken: 2012-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2010-present
Period when the impact occurred: 2020-present

1. Summary of the impact

This report describes a case of showing the steps in simulator knowledge transfer from petroleum to water industry. Process simulators are a key digital technology for holistic understanding process phenomena, competency building, assurance of process integrity and optimization of process performance. Due to legal requirements for operator training, process simulators are widely used in high hazard industries such as in petroleum and nuclear industry. However, in other industries without legal requirements and with tight economic leeway (such as in the water industry), the use of advanced digital technologies is in its infancy. Currently, OsloMet and partners are applying for funding to build competency and optimize operation in the water industry.

2. Underpinning research

The underpinning research is concentrated in three other projects:

A. Process simulator training programs project 2011-2017

During the «Process simulator training programs»-project (2011-2017) the use of dynamic process simulators in academia and petroleum industry was studied. The goal of the project was to find the best educational approaches and didactic frameworks that provide optimal learning outcomes, i.e. research and development on process simulator training programs.

The first part of the research project was to gather experiences on dynamic simulator utilization for educational purposes in academia and industry. The second part of the research project was to find out which pedagogical approaches/ didactic frameworks gave best learning results (training program).

The main findings were:

1. (Komulainen, et al. 2012) Large-scale process simulators as additional learning tools in engineering courses improve learning effect and motivate students.
2. (Komulainen, Sannerud, 2014) Simulator training in industry is improves safety and plant integrity. Annual simulator training increases process operator efficiency increases by 30% and avoids on average 3 of shut downs per year. Restricting factors to simulator training are availability of instructors and simulator rooms.
3. (Komulainen & Sannerud 2018) Further research in simulator training should focus on 3A. Individual technical skills simulator training prior to team sessions. 3B. Digital assessment tools supporting the simulator instructors in team training sessions. 3C. Pedagogical competency support, tools and methods for simulator instructors.

Professor Komulainen was the principal investigator. The main collaborators were Professor Sannerud (pedagogics OsloMet), Mr. Løvmo (simulator supplier Kongsberg), Mr. Nordsteien (instructor at oil company Equinor), Mr. Nordhus (manager at oil company Equinor), Associate Professor Manca (process simulation in Polimi, Italy), Associate Professor Nazir (simulator training, human factors at USN), Professor Øvergård (organization psychology at USN). https://app.cristin.no/projects/show.jsf?id=351086

B. Process Simulation and Learning Technologies»-project (2015-2019).

Based on finding 2 and 3A from the "A"-project we received a PhD project. The goal of the project was to build an online feedback system that enables the process operators to train on individual technical skills prior to the team simulator training sessions. The feedback systems should act as an expert instructor during the individual training sessions. The feedback should steer the operator's awareness towards the induced problems in the scenario and provide online-support for the operators during simulator scenarios.

The main findings of the research project were:

1. Online-feedback systems help steering trainees focus, but the feedback system does not allow for complete trainee autonomy.
2. Further research should include advanced data analysis for learning from previous simulation performances and give adaptive feedback to the trainees and instructors. Professor Tiina Komulainen was the principal investigator. PhD student Laura Marcano did most of the research work in close collaboration with the PI and the co-supervisors Docent Haugen (process modeling), Professor Sannerud (pedagogics), and collaborators Mr. Løvmo (simulator), Professor Yazidi (data science) and Professor Manca (process simulation). https://app.cristin.no/projects/show.jsf?id=491696 .

C. Digital tools and competency development in water industry (2020 – present)

RFF Viken and RFF Innlandet funded projects on Digital Twin Simulator (DTS VANN) and Virtual sensors (PACBAL) have paved way for introduction of simulator technologies and advanced monitoring and control technologies in Norwegian water industry. The main findings of the research projects so far are:

1. Many simulation tools tailored for water applications are internationally available, but organizational and competency barriers have so far hindered the use of these digital tools that could maximize production, minimize pollution and optimize resource use.
2. Case examples from Norwegian petroleum industry are most important to show how simulator tools can be used in Norwegian context.
3. As instrumentation (sensors) in the water industry are scarcer (water industry is not high-hazard industry as petroleum industry), there is a high need for virtual measurements to enable resource-efficient control of the water treatment processes.
4. Development of digital competency in water industry is essential to enable effective use of digital use.

Professor Tiina Komulainen was the principal investigator (PI). OsloMet experts on machine learning (Asc. Prof. Arvind Keprate), sensors (Prof Olga Korostynska and Asc.Prof Rafael Borrajo), analytical chemistry (Asc Prof. Per Ola Rønning) and biotechnology (Hear of Studies Simen Antonsen) have contributed both in research projects and in master course on virtual sensors and control. Master student from the OsloMet/ ACIT Robotics and Control study program have

contributed as research assistants in the RFF funded projects. The industrial collaborator partners are waste resource recycling facilities VEAS at Asker and HIAS at Hamar, Norway, Oslo Municipality Water and Sewage department, process technology company Cambi, simulator technology company DHI and industrial IoT company DigiTreadConnect.

https://app.cristin.no/projects/show.jsf?id=2472964.

See also PACBAL project: https://app.cristin.no/projects/show.jsf?id=2564143

and MaxBiogas project: https://app.cristin.no/projects/show.jsf?id=2648934

https://www.oslomet.no/en/research/research-projects/maxbiogas-project

https://uni.oslomet.no/maxbiogas/

3. References to the research

Komulainen, T. M., Sannerud, R., Nordsteien, B., Nordhus, H. Economic benefits of training simulators. World Oil, 2012; R61. https://hdl.handle.net/10642/1544

Komulainen TM, Sannerud AR. Learning transfer through industrial simulator training: Petroleum industry case. Cogent Education 2018 (2331-186X) Vol. 5. http://dx.doi.org/10.1080/2331186X.2018.1554790

Marcano L, Haugen F, Sannerud R, Komulainen TMK. Review of simulator training practices for industrial operators: How can individual simulator training be enabled? Safety Science. 2019; 115:414-424 https://dx.doi.org/10.1016/j.ssci.2019.02.019

Marcano L, Manca D, Yazidi A, Komulainen TM. A methodology for building a data-enclosing tunnel for automated online-feedback in simulator training. Computers and Chemical Engineering. 2020;132 https://dx.doi.org/10.1016/j.compchemeng.2019.106621

Komulainen, Tiina M. ; Baqeri, A. Malik; Nermo, Einar; Keprate, Arvind ; Saltnes, Torgeir; Jansen, Katrine M.; Korostynska, Olga (2023). Estimation of effluent nutrients in municipal MBBR process. 8 s. Linköping Electronic Conference Proceedings. https://doi.org/10.3384/ecp200037

Komulainen, Tiina; Mukhtar, Bilal; Ødegaard, Truls; Johansen, Hilde; Haualand, Kristine; Jonassen, Kjell Rune; Antonsen, Simen (2023). Modeling and control of WRRF biogas production. Linköping Electronic Conference Proceedings. https://doi.org/10.3384/ecp200027

4. Details of the impact

Impact of DTS Vann project 2020-2021:
According to Viken County Municipality's policy (Horne, 2019), stricter environmental and climate requirements as well as major socio-demographic changes represent long-term challenges for sustainable development in Viken County Municipality. The county municipality must facilitate new green industries based on renewable resources and innovative technology.
Our project team aims to meet these challenges with a main project within strategic investment area 1. Climate, environment and energy/water and sewage as well as 4. Technology: digitization and process technology.
Our project supports sustainability goals 6. clean water, 14. life under water and 9. industry and innovation.

Population growth and climate change increase the amount of wastewater and storm water in Viken County Municipality. In order to meet the future requirements for better water quality and greater water purification capacity without major investments in a new building, it is absolutely essential to invest in innovative technology for knowledge building, process optimisation, energy efficiency, minimization of environmental impact and providing a greener working environment. The preliminary project will develop technical requirements specification for multi-functional digital twin simulator and compare existing simulator products and establish partnerships with technology companies and research institutes in Viken County Municipality. The main project will create new technological innovations and increase synergies in business life in the Viken area.

Regional social significance: For society, there is a need to increase innovation in water supply and water purification in order to solve a societal problem, the water purification of the future. As climate change means more stormwater and larger cities produce more polluted water, the treatment capacity and quality of purified water must be increased using science-based methods. The main project responds to sustainability goals 6 on clean water, 14 on life underwater and 9 on industry and innovation. For the Oslo region, this means cleaner water in the Oslo fjord as untreated discharge can be minimized and the quality of purified water increased.

Regional value creation for the public sector: The main project will develop a multi-functional digital twin simulator for water treatment plants and similar facilities. The digital twin simulator will enable data and model-based predictive operational support, process optimisation, testing of process changes, and competence building among the operators and engineers at water treatment plants. The solution must provide new knowledge that can also be used at other water processing plants.

Regional value creation for the private business community: For local businesses, the project provides the opportunity to develop new third-party solutions for digital twin simulators. The main project will create new networks and bring together public sector water industry (VEAS, NRVA, Hias, Oslo Water and Sewage dept.), local technology companies (Cambi, DigiTread Connect, DHI) , universities (OsloMet, USN) and new players.

There is also a **great potential academic impact** of the proposed research (MaxBiogas project 2022-2025), by developing novel virtual sensors of unmeasured variables (and their probability distributions) and key performance indicators for sustainability, production efficiency and safety, that in combination with stochastic model predictive control and real-time optimization can give more reliable control results for biogas production.
The potential impact on environment Wastewater treatment is one of the largest contributors to eutrophication of coastal and fjord areas.

So far, Norwegian water industry is dominated by traditional control technologies. By focusing on resource utilization and value creation, MaxBiogas will develop state-of-the-art simulators for process optimization, advanced control and knowledge building.

5. Sources to corroborate the impact

The most important sources are the collaboration partners. (Specific individuals mentioned in the text above.): Equinor, HIAS WRRF, Oslo Water and Sewage dept, Veas WRRF.

Simula_Simula_Case_1

Institution: Simula
Administrative unit: Simula
Title of case study: National Digital Safety and Security
Period when the underpinning research was undertaken: 2012 - 2019
Period when staff involved in the underpinning research were employed by the submitting institution: 2001-today
Period when the impact occurred: 2015-today

1. Summary of the impact

The research contributed to and, in some cases, shaped the following:

- New national legislation on security ("Sikkerhetsloven")
- New national legislation on digital foreign intelligence and its parliamentary control ("Etterretningsloven")
- Incentive mechanisms for formation of an alternative core fiber infrastructure in Norway
- The Norwegian regulation on the use of Chinese providers of 5G equipment
- The formation of a national Cyber Crime Centre
- The formation of a centre of coordination between "Etterretningstjenesten" (foreign intelligence), the Police Security Agency (national intelligence) and the National Security Agency (NSM) on the handling of cyberattacks
- The formation of Simula UiB – a research unit in the Simula Group dedicated to cryptography and code theory

2. Underpinning research

This impact case started with research on resilient networking in 2006. An example of the output from that time is given in [reference 1, section 3]. The success of the research group led to the Prime Minister calling upon Olav Lysne in 2014 to lead a commission – the "Lysne-I commission" – giving advice on the national resilience of Norway [ref 3, sec 3]. Lysne led a group consisting of nine experts in different domains that gave a series of advice to the Government. Here we highlight the pieces of advice that was acted upon by the Government, and where Lysne personally played a defining role in forming the rationale for the advice.

The Lysne-I commission analysed the chain of digital services that underpinned a group of critical digital applications in Norway. Lysne identified that these applications all were 100% dependent on the nationwide core infrastructure of one single telecom provider. He advised that the Government should take steps to nurture a second provider to build a competing and nonoverlapping nation-spanning infrastructure.

The Lysne-I commission examined different security agencies that all had a role in countering cyber-attacks. Lysne found that the collaboration between the agencies was far short of satisfactory and advised that a permanent cyber-coordination centre with participation from all three agencies should be established.

The Lysne-I commission examined the national Police, and their ability to investigate incidents that wholly or partly took place in the digital domain. Lysne found that this ability was short of satisfactory and advised that the Police should establish a National Cyber Crime Centre (NC3), modelled after a centre in the Netherlands.

Through a series of interviews, the Lysne-I commission learned that the authorities had serious problems in recruiting cryptographic expertise that could receive security clearance. An analysis of the Norwegian education output showed that almost no Norwegian experts in the area were educated. The commission advised that a centre for research and education in cryptography should be established.

The Lysne-I commission examined how national legislation would allow the Government to intervene if it found that digital equipment developed in non-friendly states was being procured for national critical infrastructure. No such legislation existed, and Lysne advised that such legislation should be made.

After this, in 2015, Lysne was asked to lead a second commission for the national government – the "Lysne-II commission". This second commission consisted of five expert members, and was asked to give advice on if and how Norwegian Foreign Intelligence should be given access to information from the fibre cables crossing the Norwegian borders [ref. 4 sec. 3]. The research involved an analysis of what information can be found on such cables now and in the future, understanding the privacy issues that drove the discussions following the Snowden revelations, and understanding the limitations given by international law – particularly the European Convention on Human Rights. The commission devised a system of oversight and control of such a system to safeguard against abuse.

For self-containment we mention the following case, which is also described in the impact cases named "Center for Resilient Networks and Applications", and "Simula Springer Briefs":

In 2018, Olav Lysne published a book studying the details of how one can investigate digital equipment that one does not trust [ref 4, sec 3]. The backdrop of this investigation was the controversy surrounding Chinese providers of equipment to 5G networks in western countries. Based on this book, he was personally asked to frame a Norwegian policy on the matter [ref 5, sec 3].

Lysne's book from 2018 found its way to several government agencies in western countries, and Lysne was invited to visit several of them. The impact of these visits is impossible to quantify, but an opinion piece in Harvard Business Review indicates that it made some impression [Ref 1, sec 5].

Lysne has worked at Simula as Research Professor since 2001. He has held several management positions. Presently he is the director of SimulaMet.

3. References to the research

1. Kvalbein A, Hansen AF, Cicic T, Gjessing S, Lysne O. Multiple routing configurations for fast IP network recovery. IEEE/ACM Transactions on networking. 2008 Jul 25;17(2):473-86. https://doi.org/10.1109/TNET.2008.926507
2. Lysne O. The Huawei and Snowden Questions: Can Electronic Equipment from Untrusted Vendors be Verified? Can an Untrusted Vendor Build Trust Into Electronic Equipment? Springer Nature; 2018. https://link.springer.com/book/10.1007/978-3-319-74950-1
3. Lysne-I commission, Digital Sårbarhet – sikkert samfunn, Norges offentlige utredninger 2015:13 (Lysne was the leader of a cross-disciplinary commission with 9 members) https://www.regjeringen.no/contentassets/fe88e9ea8a354bd1b63bc0022469f644/no/pdfs/nou201520150013000dddpdfs.pdf
4. Lysne-II commission, Digitalt Grenseforsvar, Forsvarsdepartementet 2016. (Lysne was the leader of a cross-disciplinary commission with 5 members). https://www.regjeringen.no/contentassets/ca1f705dbebd48cb9a61889d4cfee6bf/digitalt-grenseforsvar-lysne-ii-utvalget.pdf

5. Lysne O. Norske mobilnett - en vurdering av potensielle regulatoriske regimer knyttet til leverandørbildet. Research commissioned by the Norwegian Government 2019. (This document is classified – upon request we can ask the Government to allow the evaluators to read a redacted paper-copy).

4. Details of the impact

The process of creating the impact was relatively straightforward. In most cases the impact was based on applied research commissioned for the purpose of solving problems for the Government.

There were two critical steps in making this happen. First, we had developed a standing where we were a natural choice for the government for these assignments. This involved a long history of high-quality academic research on resilience in computer systems and networks. It also involved making good strategic choices on research topics, thus creating a situation where we were the most prominent Norwegian experts in a field in which the Government needed to develop policies. The second critical step was to perform the commissioned work at high scientific standards and communicating the findings in a way that was understandable to politicians, to bureaucrats and to the public. The latter part of this required Lysne to give more than 50 public talks and write 10-15 newspaper opinions.

The impact stemming from the book "The Huawei and Snowden Questions", as indicated by the piece in Harvard Business Review, are mainly by invited talks, word of mouth, and through the credibility that Lysne already had acquired through his previous work.

The contribution of experts from outside Simula to the work reported needs be mentioned. In the two commissions led by Lysne, there were significant contributions from other experts, and the different impacts of each commission were very broad. We have, however, concentrated on the impacts from these commissions for which Lysne personally was a main driving force.

The beneficiaries of the impact are the Norwegian state and the Norwegian population in general.

The nature of the impact is that the state now has structures and legislation in place that make Norway a safer place for its population.

Evidence or indicators of the impact is given in the actual legislation that has been changed, the actual regulation of use of 5G equipment from certain countries, the fact that the footprint of Huawei in the Norwegian telecom network is being reduced and the actual institutions that have been built.

The dates of these impacts are

- New security act on 1st of January 2019.
- New act on foreign intelligence on 1st of January 2021
- Establishment of a National Cyber Crime Center 2019
- The formation of a centre of coordination between "Etterretningstjenesten" (Norwegian foreign intelligence), the Police Security Agency (national intelligence) and the National Security Agency (NSM) on the handling of cyberattacks in 2017
- Funding of Simula UiB from the national budget in 2018.
- Regulation of Chinese providers to the national 5G infrastructure in 2019
- Investments promoting a second core fiber infrastructure in Norway 2019-2020.

In 2024 Lysne is again asked to lead a government commission, this time on national autonomy in critical digital infrastructures. The results of this commission will be reported in the next evaluation.

He is also a standing member of the Norwegian Parliamentary Oversight Committee on Intelligence and Security Services (EOS-utvalget https://eos-utvalget.no/en/home/).

5. Sources to corroborate the impact

1. *Illustration of the impact that Lysne´s work on supply chains of 5G equipment has been part of the international debate on the issue.* **Cybersecurity Is Putting Customer Trust at the Center of Competition, Harvard Business Review, March 2019** https://hbr.org/2019/03/cybersecurity-is-putting-customer-trust-at-the-center-of-competition
2. *National investments in an alternative core fiber infrastructure in Norway, as advised by the Lysne-I commission:* **Stortingsmelding 28 (2020-2021).** https://www.regjeringen.no/no/dokumenter/meld.-st.-28-20202021/id2842784/?ch=3
3. *New legislation on government control of providers for equipment for critical digital installations as advised by the Lysne-I commission:* **Lov om nasjonal sikkerhet (Security Act) § 9-4** https://lovdata.no/dokument/NL/lov/2018-06-01-24?q=Sikkerhetsloven
4. *New legislation on foreign intelligence and lawful interception of traffic traversing the national border in fiber channels as adviced by the Lysne-II commission.* **Lov om Etterretningstjenesten (Act on foreign intelligence), Chapters 7 and 8.** https://lovdata.no/dokument/LTI/lov/2020-06-19-77 (in English: https://lovdata.no/dokument/NLE/lov/2018-06-01-24)
5. *National requirement that providers of 5G equipment from certain countries should not be used in more than 50% of the base stations for any given telecom provider. This was advised by to the Government by Lysne in a commissioned nonpublic whitepaper called "Norske mobilnett - en vurdering av potensielle regulatoriske regimer knyttet til leverandørbildet".* **Telenor vraker Huawei etter sikkerhetskrav fra regjeringen, NRK 13th of December 2019.** https://www.nrk.no/norge/telenor-vraker-huawei-etter-sikkerhetskrav-fra-regjeringen-1.14821794
6. *Creation of a national center for cybercrime as advised by Lysne's first commission.* **National Cyber Strategy for Norway, measure 4** (Many measures in the strategy are based the Lysne I-commission, but we choose to highlight the formation of NC3, as this was championed by the commission) https://www.regjeringen.no/contentassets/c57a0733652f47688294934ffd93fc53/national-cyber-security-strategy-for-norway.pdf
7. *The formation of a centre of coordination between "Etterretningstjenesten" (foreign intelligence), the Police Security Agency (national intelligence) and the National Security Agency (NSM) on the handling of cyberattacks as advised by the Lysne-I commission.* **Felles cyberkoodineringssenter (FCKS) vert etablert, NSM** https://nsm.no/om-oss/historien-om-nsm/felles-cyberkoordineringssenter-fcks-etableres
8. *Formation of a research unit working on cryptography and code theory***. Regjeringen med millionsatsing mot dataangrep, E24, 9th of May 2018.** *https://e24.no/teknologi/i/9vkvvr/regjeringen-med-millionsatsing-mot-dataangrep*

Simula_Simula__Case_2

Institution: Simula
Administrative unit: Simula
Title of case study: Centre for Resilient Networks and Applications
Period when the underpinning research was undertaken: 2012 - today
Period when staff involved in the underpinning research were employed by the submitting institution: 2012 – today
Period when the impact occurred: 2014 - today

1. Summary of the impact

Key impacts from research in communication systems at Simula are as follows:

- Establishment of the Center for Resilient Networks and Applications (CRNA) as a permanent research centre.
- Development of the NorNet testbed for long-term, vendor-independent monitoring of Norwegian mobile networks.
- Investigation and formulation of a policy that led to the national requirement that providers of 5G equipment from certain countries should not be used in more than 50% of the base stations for any given telecom provider.

2. Underpinning research

The roots of CRNA go back to a research activity on resilient networks started at Simula in 2006 by Professor Olav Lysne. Over the years, this activity developed in the direction of experimental research based on measurements, receiving a strong focus from around 2012. Then, in a series of studies from Simula between 2014 and 2019, researchers advanced the understanding of resilience in mobile broadband networks. The story begins with the NorNet Edge platform, unveiled by Dr. Kvalbein and his team in 2014 (paper 1 in section 3). This extensive network, consisting of over 400 measurement nodes across Norway, marked a significant leap in assessing and comparing network performance nationwide.

NorNet enabled a series of studies on network reliability also led by Dr. Kvalbein. These studies revealed that while more than 20% of stationary connections experienced significant downtime, using multiple networks simultaneously could greatly enhance reliability (paper 2 in section 3). Further exploration into network challenges continued in 2015 with insights into the nature and patterns of packet loss in cellular networks (paper 3 in section 3). This study highlighted that many issues extended beyond the radio access network. By 2017, Dr. Elmokashfi expanded the research to include network availability. Their findings indicated the potential for dual-network usage to significantly boost network reliability, particularly for stationary nodes (paper 4 in section 3).

The story took a geopolitical turn in 2019 with a study on Huawei's involvement in 5G networks. Amidst cybersecurity concerns, Professor Lysne et al. provided a nuanced perspective on the implications of banning Huawei from 5G network construction, highlighting potential delays in 5G rollout and suggesting strategies like multi-vendor deployments.

Collectively, these studies from CRNA at Simula not only shed light on the technical aspects of mobile broadband networks but also touched upon the broader geopolitical dimensions, significantly enriching our understanding of telecommunications as a critical infrastructure for modern society.

Professor Olav Lysne, as the initiator of the research that led to the creation of CRNA, has been a constant guiding force since the centre's inception. Dr. Amund Kvalbein, serving as the head of CRNA from 2013 to 2014, laid the foundation for its early achievements before departing for the industry in 2014. He was succeeded by Dr. Ahmed Elmokashfi, who led the centre from 2014 to 2022, significantly advanced its research scope before he also left for industry. The current leadership under Dr. Haakon Bryhni, commencing in 2022, marks a new phase of innovation and growth for CRNA for the next decade.

3. References to the research

1. Kvalbein A, Baltrunas D, Evensen K, Xiang J, Elmokashfi A, Ferlin-Oliveira S. The Nornet Edge platform for mobile broadband. Computer Networks, 2014, Volume 61, pages 88-101. https://doi.org/10.1016/j.bjp.2013.12.036
2. Baltrunas D, Elmokashfi A, Kvalbein A. Measuring the reliability of mobile broadband networks. In Proceedings of the 2014 conference on internet measurement conference, 2014, Nov 5 (pp. 45-58). https://doi.org/10.1145/2663716.2663725
3. Baltrūnas D, Elmokashfi A, Kvalbein A. Dissecting packet loss in mobile broadband networks from the edge. In 2015 IEEE conference on computer communications (INFOCOM), 2015, Apr 26 (pp. 388-396). https://doi.org/10.1109/INFOCOM.2015.7218404
4. Elmokashfi A, Zhou D, Baltrünas D. Adding the next nine: An investigation of mobile broadband networks availability. In Proceedings of the 23rd Annual International Conference on Mobile Computing and Networking 2017 Oct 4 (pp. 88-100). https://doi.org/10.1145/3117811.3117842
5. Lysne O, Elmokashfi A, Schia NN, Gjesvik L, Friis K. Critical communication infrastructures and Huawei. InTPRC47: The 47th Research Conference on Communication, Information and Internet Policy 2019 Jul 24. https://dx.doi.org/10.2139/ssrn.3426222
6. Lysne O. The Huawei and Snowden Questions: Can Electronic Equipment from Untrusted Vendors be Verified? Can an Untrusted Vendor Build Trust into Electronic Equipment? Springer Nature; 2018. https://link.springer.com/book/10.1007/978-3-319-74950-1

4. Details of the impact

The significance of digital infrastructure is steadily increasing. The Ministry of Transport and Communications had realized the need to understand and monitor different parts of the digital infrastructure. In 2006, the ministry supported a five-year project about resilient networks and applications that was renewed in 2010, both initiated by Professor Lysne. Within this project, Simula has provided research, education, innovation, policy advice, and other services. Simula has, furthermore, established a unique infrastructure monitoring Norwegian telecommunications providers, releasing an annual report of the performance of the telecommunications infrastructure [ref. 1 sec. 5]. In 2014, the Ministry of Transport and Communications transformed the project into the permanent Center for Resilient Networks and Applications (CRNA), providing an annual allowance of 8 million NOK. Later, the responsibility and funding for CRNA has shifted to the Ministry of Local Government and Regional Development.

CRNA illustrates nicely the modus operandi of Simula. First, by way of dialog, building trust, and providing results, Simula was able to convince the government of the need for long-term commitment into a scientific area within Simula's scope. The long-term financial support provides an opportunity for Simula to carry out relevant research, education, and innovation. Second, the Ministry of Transport and Communications has given Simula a clear mandate without interfering in its day- to-day activities or strategic research choices. Third, Simula is intent on providing services to society in return for the funding. Thus, when situations arise within the scope of CRNA, Simula

investigates at its own initiative and communicates its findings to the relevant governmental body. An illustrative example is when the Norwegian newspaper Aftenposten in 2014 published findings possibly indicating the illegal surveillance of key institutions such as banks and government bodies by means of so-called IMSI catchers [ref. 2, 3 sec. 5]. As Aftenposten published its data, Simula assessed the data and communicated the results to the relevant government body, in this instance the Norwegian Communications Authority. Subsequently, Simula acted as an independent scientific advisor to the government to assess the validity of Aftenposten's claims.

In 2018, Professor Lysne published a book investigating the details of how one can investigate digital equipment that one does not trust [ref. 6 sec. 3]. The backdrop of this investigation was the controversy surrounding Chinese providers of equipment to 5G networks in western countries. Based on this book, he was personally asked to frame a Norwegian policy on the matter [ref. 6 sec. 5]. This policy led to the national requirement that providers of 5G equipment from certain countries should not be used in more than 50% of the base stations for any given telecom provider [ref. 7 sec. 5].

Lysne's book also found its way to several government agencies in western countries, and Lysne was invited to visit several of them. The impact of these visits is impossible to quantify, but an opinion piece in Harvard Business Review indicates that it made some impression [ref. 8, sec. 5].

CRNA has further provided Simula with a strong platform for further scientific development. The research infrastructure established for the monitoring of telecommunication providers [NorNet Edge; ref. 1 sec. 3] has been a platform to establish a large European Union (EU) project [MONROE; ref. 9 sec. 5].

5. Sources to corroborate the impact

1. Norske mobilnett – Annual status reports from the Centre for Resilient Networks and Applications, archive of reports: https://www.simulamet.no/research/research-departments/center-resilient-networks-and-applications-annual-reports
2. Stortinget og statsministeren overvåkes. Aftenposten, December 14, 2014. https://mm.aftenposten.no/stortinget-og-statsministeren-overvakes/
3. PST: Ikke funnet grunnlag for falske basestasjoner. VG, March 26, 2015. https://www.vg.no/nyheter/innenriks/i/J09EX/pst-ikke-funnet-grunnlag-for-falske-basestasjoner
4. Vår felles digitale grunnmur. Stortingsmelding 28, 2020-2021. https://www.regjeringen.no/contentassets/e8441e5b035a4e18bbebf74737530c2f/no/pdfs/stm202020210028000dddpdfs.pdf
5. EKOMROS 2020: Den digitale grunnmuren satt på prøve. Nasjonal kommunikasjonsmyndighet, 2020. https://nkom.no/rapporter-og-dokumenter/ekomros2020/_/attachment/download/9400adbc-e7d1-4f1c-9efc-be3890a1ff5c:5b26cea852f4cf29decbd073bf838fe59c7daac4/EkomROS%202020.pdf
6. Lysne O. Norske mobilnett - en vurdering av potensielle regulatoriske regimer knyttet til leverandørbildet. Research commissioned by the Norwegian Government 2019. (This document is classified – upon request we can ask the Government to allow the evaluators to read a redacted paper-copy).
7. Telenor vraker Huawei etter sikkerhetskrav fra regjeringen. NRK, December 13, 2019. https://www.nrk.no/norge/telenor-vraker-huawei-etter-sikkerhetskrav-fra-regjeringen-1.14821794
8. Illustration of the impact that Lysne´s work on supply chains of 5G equipment has been part of the international debate on the issue. Cybersecurity Is Putting Customer Trust at the Center of Competition, Harvard Business Review, March 2019

https://hbr.org/2019/03/cybersecurity-is-putting-customer-trust-at-the-center-of-competition
9. Measuring Mobile Broadband Networks in Europe (MONROE). https://cordis.europa.eu/project/id/644399

Simula_Simula_Case_3

Institution: Simula
Administrative unit: Simula
Title of case study: Evidence-based Digitalization of the Public Sector in Norway
Period when the underpinning research was undertaken: 2010-today (main period, some research before that)
Period when staff involved in the underpinning research were employed by the submitting institution: 2010-today (main period)
Period when the impact occurred: 2010-today (main period)

1. Summary of the impact

The research, knowledge transfer, and advisory function described in this impact case are believed to have had a substantial positive impact on software development productivity, cost control, time control, and benefits realization in the public sector in Norway, and through this, a positive impact on the productivity, wealth and well-being of the Norwegian society. The underlying principle of the work, evidence-based software engineering, is now spread worldwide as an effective way to solve challenges related to software development.

2. Underpinning research

The underpinning research consists of a high number (>100) of empirical studies with results on what leads to success and what is connected with failure in software development. The emphasis on *empirical* studies to extract evidence-based software engineering knowledge has been a key element of the software engineering research ever since Simula was established in 2001, and is still central. In particular, the ability to conduct experimental software engineering research in contexts closer to real life than what others do has been a quality characteristic of our research. The process of formulating the research problems and transferring practical results to the software industry is to some extent founded in *Evidence-based software engineering*, which was developed as a research field by Magne Jørgensen at Simula together with Tore Dybå at SINTEF and Barbara Kitchenham at the University of Keele. The work on evidence-based software engineering received the 2014 ACM Sigsoft Award for the most influential research during the last ten years.

Examples of empirically-based research results underpinning the impact on software development outcomes in the public and private sectors are:

- Guidelines on how to succeed in realizing the benefits of software development. Concrete results demonstrate the extended responsibilities of the development team in realizing benefits, which traditionally just have had the role of delivering software in accordance with a requirement specification. It also includes results on how to formulate the planned benefits so that they can be evaluated and managed. Research on benefits management has been conducted in the period 2016-2023. Key researchers: Magne Jørgensen and Jo Hannay, both at Simula.
- Better methods for cost and benefits estimation, including results on better group-based estimation and more realism in the assessment of the uncertainty of cost estimates. Research of cost estimation has been part of the group's work since the establishment of the group until today. Key researchers: Magne Jørgensen, Torleif Halkjelsvik and Jo Hannay, all at Simula.

- Evidence-based results on the use of contracts in software development projects. In particular, the documentation of the negative effect of fixed-price contracts on software development success in many contexts, together with the understanding of the mechanisms leading to this negative effect, has been important. Key researchers: Magne Jørgensen, Stein Grimstad and Parastoo Mohagheghi, all at Simula when the research was conducted.
- Results on how to improve the recruitment of software developers and how to select among candidate providers for software development work. This work has provided results on what are good and bad practices for evaluating and selecting developers and companies. In addition, it has documented the very large difference in performance among developers and companies, and the low correlation between performance and selection indicators typically found in CVs and project proposals, such as length of experience. As part of the work, we have proposed a method for selection of providers called "trialsourcing" (trying out more than one provider on parts of the project), which has been used with success by governmental agencies, and emphasized the need for large, realistic work-sampling testing when hiring software developers. Key researchers: Magne Jørgensen, Simula.
- Results on what are the key elements of making agile software development work well, and reporting results on that agile software development works well on large as well as smaller projects. Key researchers: Magne Jørgensen and Stein Grimstad, both at Simula when the research was conducted.

3. References to the research

Halkjelsvik, T., & Jørgensen, M. (2012). From origami to software development: A review of studies on judgment-based predictions of performance time. *Psychological bulletin*, *138*(2), 238. (Cited by 133).
https://psycnet.apa.org/record/2011-25198-001

Jørgensen, M. (2016). A survey on the characteristics of projects with success in delivering client benefits. *Information and Software Technology*, *78*, 83-94. (Cited by 93).
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https://www.sciencedirect.com/science/article/pii/S0263786317301813

Jørgensen, M. "Do agile methods work for large software projects?." *Agile Processes in Software Engineering and Extreme Programming: 19th International Conference, XP 2018, Porto, Portugal, May 21–25, 2018, Proceedings 19*. Springer International Publishing, 2018. Cited by 64).
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Jørgensen, M., Bergersen, G. R., & Liestøl, K. (2020). Relations between effort estimates, skill indicators, and measured programming skill. *IEEE Transactions on Software Engineering*, *47*(12), 2892-2906. (Cited by 6)
https://ieeexplore.ieee.org/abstract/document/8999628

NB: These articles are far from complete in presenting the results underpinning the impact described in sections 2 and 4, which is about a much wider range of empirical results on how to improve software development.

4. Details of the impact

To make strong claims regarding the impact of our research, knowledge transfer, and advice-giving on improved software development processes in the public sector would require other means than what we have available. Typically, a change in the work process is made by people impacted by many sources, where our research results are mainly indirect or contributory reasons for the change. In addition, the evaluation of the effect of the change poses complications in itself.

For the above reasons, we have chosen to describe the activities on spreading knowledge about good, evidence-based software development practices. The underlying assumption is that our extensive outreach to the software industry with evidence-based knowledge, recommendations, and advice-giving has influenced and impacted people in the public sector in making the decisions to change work practices. The belief in this is supported by personal communication with involved people and the references in 5.

The outreach activities of the research group include the following:

- Articles in national and international magazines directed towards practitioners. This includes articles in Computerworld Norway (where we had a bi-weekly, later monthly, column for more than 10 years, digi.no (where we have had several articles/letters/interviews), articles in national newspapers and international software magazines (such as IEEE Software and IT Professionals). In total, more than 120 articles directed towards software professionals have been produced, most of them the last 10 years.
- Presentations at national and international practitioner conferences, such as the national Smidig conference and international XP conference. In total, more than 50 such presentations have been made, most of them the last 10 years.
- A high number of presentations/transfers of research to individual public sector organizations. As an example, we have had presentations for the top IT management and for software developers in *all* of the largest Norwegian public organizations. In total, about 100 presentations of this type have been given, most of them the last 10 years.
- Established in 2014, the HIT network has more than 600 members from the public and the private sector. The network has been led by people from the research group. It has been, and still is, an important arena for transfer of research results and the spread of good practices between the network members. Since 2014, there have been 3-4 seminars with 80-150 industry participants each year.
- Since 2021 the research group has published one newsletter each week with practice-oriented results on software development sent to all its members.

Other reasons to believe in a positive impact from our evidence-based recommendations on the software development practices in the public sector include:

- We have been asked to give advice to several public organizations on how they should organize their software development work. This includes invitations for advice-giving from the prime minister's office, several government ministries (KDD, KD, and Finance), the National Audit Office, and most of the largest public organizations with software development in Norway. We have also given advice to more than 10 private companies, both in Norway and internationally.

- Research-based advice has been given to around 100 individual software projects in the public sector since 2016 through being a member of the national Digitalization Advisory Board (Digitaliseringsrådet).
- One medium-large consultancy company (Scienta) is a spin-off company from Simula by one of the prior Ph.D. students (Stein Grimstad). This consultancy company is based on the evidence-based principles developed within the group and gives advice and support to the software development of public and private organizations. All new employees of that company have to participate in training, held by a member of our research group (Magne Jørgensen), to become evidence-based software developers.

As stated above, it is hard to document the nature and extent of the impact of our extensive transfer of research results. The observation that, especially in the public sector, the actual practices more and more are following our recommended software development practices is, however, consistent with the fact that our work has had a substantial impact. Two examples:

- Before we did our studies on the negative effects of fixed-price contracts, most software development projects in the public sector used fixed-price or similar types of contracts. Today, nearly all use the types of contracts recommended by us. This has amongst others the consequence that the selection of providers is to a larger degree based on skill rather than on low price. Our result on the surprisingly large negative effect of fixed price got much attention in the media, including the main newspaper in Norway (Aftenposten), which is likely to have contributed to the spread of better contracting practices.
- Benefits management practices have improved in the public sector the last years. It is not unreasonable to attribute an important part of this to our research and spread of research results. Benefits management practices, as documented in process guideline documents by Norwegian Digitalisation Agency (DigDir) and The Norwegian Agency for Public and Financial Management (DFØ), have been changed to be more consistent with our evidence-based recommendation by people well aware of our research results.

5. Sources to corroborate the impact

Evidence documenting actual impact are, as stated earlier, hard to find, but the following references may indirectly indicate the impact:

- The ACM Sigsoft 2014 awarded our work on evidence-based software engineering with the award for the most influential paper last ten years, see: www2.sigsoft.org/awards/impactpaper
- One of the research group's members (Magne Jørgensen) was ranked by Computerworld Norway to be one of the fifty most influential ("IT power") professionals (and the highest ranked researcher) within ICT in Norway in 2012, 2013, and 2014 (ranking discontinued). See for 2014: www.cw.no/offentlig-sektor/it-makt-i-norge-2014-topp-100/63329
- The yearly experience report from Digitaliseringsrådet (where we have a member and contribute with research-based advices) report that the organizations are following the advices and find them useful. See the experience reports: www.digdir.no/digitaliseringsradet/digitaliseringsradets-erfaringsrapportar-og-erfaringsseminar/1871
- The editor of Aftenposten (influential Norwegian newspaper) wrote about our research in 2017. www.aftenposten.no/meninger/leder/i/azx34/aftenposten-mener-difi-boer-samordne-kunnskap-om-offentlige-ikt-anskaffelser (17
- Several public reports on how to develop software in the public sector include references to our research. See for example the section on better management of digitalization projects in the public sector in governmental strategy document "Digital Agenda for Norway": "Digital agenda for Norge – IKT for en enklere hverdag og økt produktivitet" (Stortingsmedling 27, 2015-2016)" and the report from the productivity commision (NOU

2016:3): “Ved et vendepunkt: Fra ressursøkonomi til kunnskapsøkonomi Produktivitetskommisjonens andre rapport:” https://www.regjeringen.no/contentassets/fe3e34b866034b82b9c623c5cec39823/no/pdfs/stm201520160027000dddpdfs.pdf, lovdata.no/static/NOU/nou-2016-03.pdf

- The National Audit Office’s report about the challenges and improvement potential for the digitalization in the Norwegian Police is partly based on our input, see www.riksrevisjonen.no/globalassets/rapporter/no-2017-2018/digitalisering.pdf.
- Based on the previous research in our research group the Ministry of Local Government and Regional Development (KDD) decided in 2021 to establish a national center for research on effective digitalization of the public sector with 5.5 mNOK yearly funding. www.forskningsradet.no/contentassets/a8da6b1c63814652b314af5d4950e940/2023_kdd-tildelingsbrev-2023-l5389897.pdf.
- The guidelines for use of the governmental model for large digitalization projects (Statens prosjektmodell), which is a model mandatory to use for all project budgeted to cost above 300 mNOK, has references to and are on several places influenced by our research. In addition, we believe that we have pushed the focus on benefits management both here and in other governmental contexts, such as Medfinansieringsordningen. Benefits management are now mandatory in many governmental digitalization contexts, conducted in a manner consistent with our research results . See for example the guidelines at: https://www.regjeringen.no/contentassets/b3bfe59c8ac84af9b303b810b8065898/veileder_digitaliseringsprosjekter.pdf.
- Group members have established themselves as leading researchers on digitalization in the public sector. This is illustrated by that we are invited to be editor and contribute with articles in a forthcoming special issue on digitalization in the public sector by the national economy magazine Magma. People from the group are also regularly interviewed about digitalization in the public sector and members of panel debates, especially about the challenged and failed public software projects. See for example: www.cw.no/ikt-norge-ledelse-offentlig-sektor/suksesskriterier-pa-agendaen/340637

Simula_Simula_Case_4

Institution: Simula Research Laboratory

Administrative unit: Simula Research Laboratory

Title of case study: Innovation and Commercialisation

Period undertaken: 2012 - 2022

Period when staff involved in the underpinning research were employed by the submitting institution: Individual periods during 2012 - today

Period when the impact occurred: 2015-today

1. Summary of the impact

Throughout the evaluation period (2012-2022), innovation and commercialisation activities have been inherent to the technology-oriented research at Simula. This process includes three complementary components. 1. The fully owned subsidiary, Simula Innovation (SI), has been central to this development by actively supporting the transfer of research to the market by assisting the creation of new services or products, and as an early investor. 2. The Simula Garage (Gründergarasjen), also part of Simula, has served as an integrated tech incubator for early-stage (pre-seed) startups, servicing both Simula and external ICT projects/start-ups. 3. Simula's research groups have conducted contract research for industrial and public sector clients based on their core research-based competence areas, and participated in due-diligence screening for SI of potential technology company investments.

Simula's research has contributed to, and in some cases shaped, the following innovation results:

- Nine commercial spin-out companies from Simula's research by the end of 2022.
- Establishment of the Simula Garage as a tech incubator, boosting entrepreneurship at Simula and collaboration with the research units.
- Simula's research competence has improved services and products in SI-owned companies to meet market needs for advanced technological solutions, leading to increased sales.
- Attracting ca. 81 MNOK of innovation funding from EU and the Research Council of Norway to the spin-out companies.
- Attracting ca. 124 MNOK of external private investments in the spin-out companies.
- Dividends and three exits amounting to approximately 70 MNOK, which has been reinvested in tech start-ups.
- Building SI's investment portfolio; as of 2022, SI had ownership in 40 companies, with a combined annual revenue of 420 MNOK and 420 employees.

2. Underpinning research

Most of the spin-out companies were created on the basis of substantial research activities at Simula, and several Simula researchers left their positions in the research units to bring their ideas to fruition. In addition, some researchers have stayed in Simula but been engaged in ongoing applied research projects in the spin-out companies. Names in italics refer to researchers who have moved full-time to spin-outs, the others are have contributed to the companies while maintaining their Simula positions.

Forzasys: Pål Halvorsen, *Ragnar Langseth*, *Tomas Kupka*

Celerway: *Audun Fosselie Hansen*, *Kristan Evensen*

Fabriscale: *Sven-Arne Reinemo*, Tor Skeie

Quine: *Stian Zeijko Vrba*, *Kristian Skarseth*, *Konstantin Pogorelov*

Augere: *Andreas Petlund*, *Haavard Espeland*, *Pia Helen Smedsrud*

Organos: Sam Wall**,** Aslak Tveito, Karoline Horgmo Jæger

Testify: *Erik Arisholm*, *Amir Yazdanshenas*, *Erik Rogstad*

Expert Analytics: *Åsmund Ødegaard*, *Olav Skavhaug*

Kalkulo: *Christian Tarrou, Trond Vidar Stensby, Øyvind Hjelle, Stuart Clark, and others*

These companies have later recruited several PhD students and postdocs who have finished their training at Simula.

3. References to the research

The companies have also frequently collaborated with Simula in new research and innovation projects when creating new products or services. This has resulted in many research papers and conference presentations. This pattern can be illustrated by a few examples from three of the companies, all spun out from Simula's Communication Systems group (Simula researchers in italics):

Forzasys:

"Automatic Event Extraction and Video Summaries from Soccer Games" by A. Mortensen, *V. R. Gaddam*, *H. K. Stensland*, *C. Griwodz*, D. Johansen, *P. Halvorsen*. In Proceedings of the International Conference on Multimedia Systems (MMSys), Singapore, March 2014, pp. 176-179.

"Bagadus: An Integrated System for Arena Sports Analytics - A Soccer Case Study" by *P. Halvorsen*, S. Sægrov, A. Mortensen, D. K. C. Kristensen, *A. Eichhorn*, M. Stenhaug, S. Dahl, *H. K. Stensland*, *V. R. Gaddam*, *C. Griwodz*, D. Johansen. In Proceedings of the International Conference on Multimedia Systems (MMSys), Oslo, Norway, February/March 2013, pp. 48-59.

For more information and papers, see: https://forzasys.com/R-and-D.html

Fabriscale:

"Making the network scalable: Inter-subnet routing in infiniband" by *B. Bogdański*, B. D. Johnsen, S.-A. *Reinemo*, J. Flich. In Euro-Par 2013 Parallel Processing: 19th International Conference, Aachen, Germany, August 26-30, 2013, pp. 685-698. Springer.

"Discovery and routing of degraded fat-trees" by *B. Bogdanski*, B. D. Johnsen, S.-A. *Reinemo*, F. O. *Sem-Jacobsen*. In 2012 13th International Conference on Parallel and Distributed Computing, Applications and Technologies 2012 Dec 14, pp. 697-702. IEEE.

Celerway:

"A NEAT approach to mobile communication" by P. Hurtig , S. Alfredsson, A. Brunstrom, *K. Evensen*, K.J. Grinnemo, *A.F. Hansen* and T. Rozenscztrauch. In Proceedings of the Workshop on Mobility in the Evolving Internet Architecture, 2017, pp. 7-12. ACM.

"Measuring and assessing mobile broadband networks with MONROE" by *Ö. Alay*, *A. Lutu*, R. Garcia, M. Peon-Quiros,V. Mancuso, T. Hirsch, et al. In 2016 IEEE 17th International Symposium on A World of Wireless, Mobile and Multimedia Networks (WoWMoM), pp.1-3. IEEE.

4. Details of the impact

Simula's innovation and commercialisation activities grew and matured throughout the evaluation period. In particular, SI focused on building a portfolio of companies that are spun out of Simula's research projects and expertise. In order to encourage more spin-outs from the research, the Simula Garage provided invaluable resources, expertise, networks and communities to its member start-up companies (free of charge), and fostered a close link between the start-ups and academia. The Garage's start-ups also served as a source for potential investment opportunities for SI, which had the benefit of observing their progress during their membership in the Garage. In addition, commissioned research engagements kept research groups closer to end users, developing an understanding of potential customer needs.

By the end of the evaluation period, SI had ownership in 40 companies with a combined annual revenue of 420 MNOK and 420 employees, spanning the following categories: Software, Network, Media, Proptech, Fintech, MedTech, and Media. Approximately half of the companies in the 2022 portfolio were either spun out of Simula's research or from the Simula Garage; the other half were

externally sourced investment opportunities, with due diligence of the technology often commissioned from Simula researchers. Some of the companies in the Simula Garage also recruited Simula researchers to critical positions, such as CTOs.

The process for augmenting the innovation and commercialisation activities at Simula took shape mainly between 2014-2019, and several companies were successfully spun out of Simula during this time, based on research conducted either before and during these years.

The process is based on a few simple principles developed by SI:

- An honest negotiation process that generated a capitalization table (detailed ownership structure) that is seen as fair both from the employee's and Simula's standpoint. The spin-outs are given full ownership of IPR with no need for licencing.
- A company should not be spun out too early, as statistically there is a long way to the market for research-driven start-ups. Incubator services are provided by the Simula Garage to accelerate both the development of the product and marketing plans.
- Investment from SI is conditioned on the readiness for sale of product and services, as this is key to attract private investment and for the company to survive in the long run. Due diligence (i.e., vetting a company's technology solution) should be performed ahead of investing.
- This implied contribution with capital from SI in matching funds from RCN and Innovation Norway. In most cases, the investment from SI was increased, securing sufficient seed money for the companies to grow.

As a result of this process, the researchers retain part ownership ("skin in the game") and sufficient salary as employees of the newly created companies. In addition, they are granted a temporary leave of absence from Simula until they experience the employment in the new company as sufficiently secure to exit Simula permanently.

This process was different from earlier operation. While several companies were established prior to 2014, these were typically short-lived due to insufficient funding and engagement from the researchers, who continued in their Simula positions.

Other key external contributions. Both the RCN and Innovation Norway were instrumental in seed funding for the companies during the most challenging period following establishment and leading up towards a ramp-up in sales revenue and/or private investments.

The nature of the impact is primarily a successful model that outlines the process for how a relatively small research institution can play a pivotal role in commercialization and innovation, by creating an agile, non-bureaucratic and trustworthy environment that stimulates researchers to engage in taking their ideas to market. There are many downstream benefits, as outlined below.

The beneficiaries of the impact are:

- *Norwegian state*
  - Creation of companies with high-skill jobs and the potential for growth.
  - Tangible societal benefits from money invested in research.
- *Customers and clients*
  - Availability of high-quality, research-based products and services.
  - High-tech solutions that address the customers' specific needs.
- *Simula Research Laboratory,* as research institution and owner
  - Remarkable track record in creating new products and services based on the research, especially considering the size of Simula and its focus on basic research.
  - Limited economic risk associated with the commercialization due to substantial ownership from very early investing. Major risk taken by the private investors.
  - A demonstrated commercialisation model from basic and applied research. This model could be adopted by other organisations with limited administration costs.
- *The researchers*

- Potential economic gain from one's own research, with limited personal risk
- Opportunity to see their research applied in society
- Alternative career paths
- Very valuable experience for further career, independent of the economic outcome, when returning to Simula, other academic institution or industry.

Evidence of the impact is shown by the success of the portfolio of investments by the end of 2022, with 40 companies generating an annual revenue of 420 MNOK and 420 jobs. The impact is particularly relevant in that half of these portfolio companies that are connected to Simula's research and the Garage, with 9 active spin-outs from Simula's research during the evaluation period. Here we highlight the following companies and impacts across four investment sectors:

Communications

- **Celerway** – founded in 2013 by Drs. Audun Fosselie Hansen and Kristian Evensen as a spin-out from Simula. Creating the only proven open source-based, mobile-first SD-WAN platform to keep business ahead of the mobile curve. The mobile-first platform enables customers to harness the power of multiple simultaneous wireless and wired connections to bring their networks where they want them to be, thus expanding the reach of their SD-WAN or edge and branch networking solutions. SI made a partial exit in 2020. Employees in 2022: 10.
- **Fabriscale Technologies** – founded in 2014 by Dr. Sven-Arne Reinemo and Prof. Tor Skeie. Fabriscale operates in the High Performance Computing (HPC) market. The company's inception was based on extensive research in network algorithms for high-performance interconnection networks conducted at Simula. Fabriscale developed the two products Wingman (fabric manager) and Hawk-Eye (monitoring real-time analytics platform) for use in HPC clusters and data centres using Infiniband interconnect networking.

Media

- **Forzasys** – founded in 2014 by Prof. Pål Halvorsen and Prof. Dag Johansen as a spin-out from Simula. Forzasys provides a complete end-to-end video and metadata solution for sports, from the production of video events to the dissemination to end-users. The aim is to provide the future video media asset management for sports, with live-streaming and archive solutions for leagues and clubs based on and integrating technology within distributed multimedia systems, machine learning and information retrieval. Customers during the evaluation period include Norsk Toppfotball, Svensk Elitfotboll, Svenske Hockey-ligaen and Telenor. Employees in 2022: 7.
- **Quine** – founded in 2016 by Drs. Stian Zeijko Vrba and Kristian Skarseth as the result of a successful EU-funded project coordinated by Simula. The team spent three years developing a back-end and database model for the media sector. The final product is a collaborative workflow tool. One of the customers is NRK, which has used the Quine products as the main tool in the production of all its TV series since 2020. Employees in 2022: 8.

Medtech

- **Augere Medical** – founded in 2018 by Associate Prof. Andreas Petlund, Pia Helen Smedsrud and Håvard Espeland. Focusing on disrupting the colorectal cancer diagnostics market, Augere has developed a decision support tool (PolypAid) for improving colon polyp detection rates during colonoscopies. This is based on further applied research on reliable technologies for clinical use within machine learning, real-time processing, and information retrieval. Employees in 2022: 6.
- **Organos Inc.** – founded in 2012 and based in Berkely, California. Organos aims to revolutionise drug development with AI-centric, heart-on-a-chip technology. Cardiovascular drug discovery lacks the data needed to efficiently and safely find novel drug candidates. Organos solves this problem by combining high-throughput screening, high content tissue models, and novel computational tools using AI and machine learning to advance drug discovery and drug development. Organos' technology is used by the FDA and major universities and have received USD 8M of academic grants supporting technology and software development, as well as USD

3.7M from California Institute of Regenerative Medicine and others. Chief Research Scientist Samuel Wall at Simula is a co-founder, and became CEO and CSO of the company in 2019. Employees in 2022: 6.

Consulting

- **Kalkulo** – founded by Simula in 2006 to take care of the commercial consulting and software development activities in a comprehensive R&D collaboration with the oil and gas division of Hydro (later Equinor). Kalkulo was significantly boosted in 2014, when Simula's research department for computational geoscience merged into the company. In total, from 2006 to 2019, Equinor bought services in Kalkulo for more than 200 MNOK, leading to two key products for geological modelling that are still seen as competitive advantages. Kalkulo also served other actors in the energy sector, including Statkraft. SI made a full exit from Kalkulo in 2019, selling it to the American company Bluware. Employees at the time of exit: 19.
- **Testify** – founded in 2010 by Prof. Erik Arisholm, the company has seen a substantial economic growth in the period 2012-2022. The company offers efficient test automation in order to enable large and/or complex software development projects to succeed in the development of high-quality software. The company has a wide range of customers, including the Norwegian Tax Administration (Skatteetaten), Sykehuspartner, the Norwegian Labour and Welfare Administration (NAV), Kongsberg Defence, Telenor and others. The company reached 45 MNOK in income and 22 employees in 2022. Employees in 2022: 22.
- **Experts Analytics** – founded in 2013 by Drs. Åsmund Ødegaard and Olav Skavhaug. With background in scientific computing, the company applies research-based methods in the modelling and implementation of tailored software solutions for industrial challenges. Their scope spans high-performance computing, system development, data science and machine learning, and advanced data visualisation. The company has a wide range of customers, including DNB and Statkraft, and has played an important role in development of the mobile payment solution Vipps. SI made a full exit in 2019. Employees in 2022: 42.

5. Sources to corroborate the impact

Several **patents** have been developed in relation to or within the spin-outs, e.g.

1. F. O. Sem-Jacobsen, O. Lysne, H. Q. Vo, A. Kvalbein. Method and apparatus for determining paths between source/destination pair. US Patent US9379971B2, 2016.
2. O. Lysne. Deadlock free network routing. US Patent US7724674B2, 2010.
3. J. C. Villanueva, T. Skeie, S.-A. Reinemo. Method of computing balanced routing paths in fat-trees. US Patent US10425324B2, 2019.
4. J. C. Villanueva, T. Skeie, S.-A. Reinemo. System and method of computing ethernet routing paths. US Patent US10855581B2, 2020.
5. D. Kaspar, K.R. Evensen, et al. Data segmentation, request and transfer method. US Patent US8516147
6. O. Lysne, A. Kvalebein et al. Resilient routing systems and methods, France, Germany, Ireland, United Kingdom EP07250596.9 national number EP1821472

There have been several news articles related to the impact, e.g.

1. Finansavisen about SI: https://www.finansavisen.no/finans/2023/10/01/8038959/ottar-hovind-i-simula-innovation-bedre-avkastning-enn-jeg-hadde-forventet
2. Finansavisen about Augere: https://www.finansavisen.no/nyheter/helse/2020/07/06/7542378/augere-medical-skal-revolusjonere-tarmkreftbehandlingen-med-kunstig-intelligens
3. Eliteserien about Forzasys: https://www.eliteserien.no/nyheter/folg-med-pa-malkongen-og-assistkongen
4. Forzasys listed as one of the 55 most innovative machine learning companies in Norway: https://futurology.life/55-most-innovative-norway-based-machine-learning-companies/

Simula_Simula_Case_5

Institution: Simula
Administrative unit: Simula
Title of case study: Simula SpringerBriefs on Computing (SSBC) series
Period when the underpinning research was undertaken: 2001-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2001-2022
Period when the impact occurred: 2016-today

1. Summary of the impact

Key impacts from the *Simula SpringerBriefs on Computing* (SSBC) series are as follows:

- SSBC is an effective dissemination tool, reaching audiences beyond typical academic publications, demonstrated by over 1.3 million downloads from Springer and the availability of digital and hardcopies through major vendors (e.g., Amazon, Google Play, OAPEN library, and even Walmart)
- This series is fully open-access, published under the CC-BY license, meaning the material can be reused for any purpose (including commercial). This promotes not only dissemination of the research, but also makes the content more available to decision and policy makers, engineers, bureaucrats, teachers, consultants and so on.
- While the majority of readers of the series are researchers and students, some of the volumes have had significant reach outside academia. The main impacts have been on:
  1. Education (from undergraduate science education to continuing education for teachers)
  2. National security awareness and policy
  3. Project planning and cost estimates in IT projects, in industry and the public sector

2. Underpinning research

The SSBC book series grew from a long and productive dissemination collaboration between Simula and the Springer publishing house, with a total of 15 books by Simula authors published with Springer from 2001 to 2016. In parallel with this collaboration, Simula was strongly involved in teaching and frequently recruited new Master's students, PhD students, and post-doctoral researchers. The teaching efforts, and in particular the recruitments of new researchers, highlighted the need for compact and accessible texts suitable for introducing students and scientists to a new field of research. This became the motivation for launching the SSBC series in 2016, and it was decided to make it part of open access program SpringerOpen to reach a larger audience.

The majority of the 12 volumes published between the SSBC launch in 2016 and 2022 were authored by Simula researchers and directly based on their research at Simula. The different volumes in this open-access series cater to different audiences. Most of the books target a broader academic audience, ranging from 1st year university students to experienced researchers, and many of the volumes have had a substantial impact within academia, as indicated by the number of downloads and other sources. However, as this case is focused on impact *beyond* academia, we mainly highlight three volumes that have had obvious (and to some degree documented) impact far outside the academic community.

These volumes are:

1. *Introduction to Scientific Programming with Python* (2020) by J. Sundnes
   -used for courses in basic programming for adult learners (continuing education) as well as students.

2. *The Huawai and Snowden Questions* (2018) by O. Lysne
   -gained worldwide attention and shaped discussions related to critical infrastructure and Norwegian National Security.
3. *Time predictions* (2018) by T. Halkjelsvik and M. Jørgensen
   -widely used in courses for industry and summarizes research that led to a government-funded research centre on managing ICT projects in the public sector.

Introduction to Scientific Programming with Python (2020): This volume's main purpose is to provide readers with a basic, practical and hands-on introduction for using Python to solve different kinds of problems. The material is based on Simula's Scientific Computing research, which has focused on simulating real-world phenomena by solving mathematical models, typically formulated as partial differential equations (PDEs). The group has a particularly strong track record in software for scientific computing, spearheaded by the late Professor Hans Petter Langtangen, ranging from advanced frameworks for solving PDEs (e.g., FEniCS), through substantial contributions to introducing Python as a widespread language for computational science, to driving a fundamental change in how computing tools are used in science education at the University of Oslo. While the SSBC volume builds on this research, and in particular on previous teaching efforts and text books by Professor Langtangen, the book is not written for experienced researchers or graduate students. Rather, the audience is expected to have only a basic (high-school level) understanding of mathematics and no prior experience with programming.

Huawei and Snowden Questions (2018): This volume answers two central questions that are crucial for digital societies – *Can electronic equipment from untrusted vendors be verified?,* and *Could trust be built into products by supporting independent verification?* – by drawing on Simula's collective expertise in Communication Systems and Software Engineering. Simula's research in Communication Systems has focused on assessing and improving the resilience and reliability of a wide range of communication networks, including interconnection networks in high-performance computing, architecture of the Internet, and the nation-wide Norwegian mobile phone network. Network architectures and algorithms are developed to provide performance, resilience and security across different types of network applications. This SSBC volume consolidates this research to provide a rich and solid context for exploring key societal considerations surrounding trustworthiness and security of digital infrastructures. With two somewhat overlapping audiences in mind – technologies and the broader interested public – the text and supporting materials are presented in order to make it easily digestible for both ICT and security professionals that need a clear technical understanding of these issues, as well as decision-makers in industry, national bodies and nation states.

Time predictions (2018): The main emphasis of the book is not on formal, mathematical models for time predictions, but rather on *judgement-based time predictions*, also known as *expert estimation,* as this forms the vast majority of time predictions made in daily and professional life.

The research underpinning this volume was generated by Simula's Software Engineering group. As mentioned above, this group studies the planning, development, testing and maintenance of complex software systems. In particular, one of the long-term research efforts has been on cost and time estimates for software system development, which has led to widespread attention and recognition from the Norwegian IT industry, including a series of popular seminars and courses. In recognition of the need for an evidence-based resource for decision makers, this volume draws on Simula's own research as well the scientific literature in order to addresses common questions around the effects of biases, tendency towards and dangers of overoptimism, and how to deploy best practices when planning large projects.

3. References to the research

- *Introduction to Scientific Programming with Python* (2020) by Joakim Sundnes link.springer.com/book/10.1007/978-3-030-50356-7
- *The Huawei and Snowden Questions: Can Electronic Equipment from Untrusted Vendors be Verified? Can an Untrusted Vendor Build Trust into Electronic Equipment?* (2018) by O. Lysne link.springer.com/book/10.1007/978-3-319-74950-1
- *Time Predictions: Understanding and Avoiding Unrealism in Project Planning and Everyday Life* (2018) by T. Halkjelsvik and M. Jørgensen link.springer.com/book/10.1007/978-3-319-74953-2
- All the volumes in the *Simula SpringerBriefs on Computing* series are displayed on Simula's homepage (www.simula.no/research/publications/simula-springerbriefs) and are available for download from Springer here: www.springer.com/series/13548

4. Details of the impact

The *Simula SpringerBriefs on Computing* (SSBC) was launched in 2016 in order to provide compact and accessible introductions to topics within Simula's main research areas and expertise. While all volumes are peer-reviewed, research-based overviews of a given topic in computing, the SSBC format allows for some flexibility in terms of the set-up, the target audience and purpose of the publication. For example, one volume might be a collection of short reports from different groups of researchers intended to provide a state-of-the-art summary for other researchers at the post-graduate level. Another volume might be a single author monograph that intends to inform decision makers about the established research that applies to salient societal issues. This adaptability makes SSBC a potentially far-reaching dissemination tool for getting the research-based knowledge to a broader audience; tailored according to topic and purpose.

The series is published by SpringerNature, which ensures the quality of the process and the final published product, and assists with the dissemination of both the free online open-access editions and the printed editions (all open-access, under the CC-BY license). This combination of free online access and availability to purchase the hardcopy makes this series more accessible to a broader audience than standard scientific publishing or outreach venues. For example, the digital copies can be downloaded directly from Springer or from other online distributors such as Google Books and OAPEN Library, but also further shared and/or adapted by readers for any purpose including commercial, as is permitted under the CC-BY license. The hardcopies are available for purchase from Springer, but also through other mass retailers such as Amazon and Walmart.

This degree of accessibility is precisely the motivation for selecting this format and publishing option. It does, however, make it challenging to measure the precise reach and impact of the series, as the download statistics provided by Springer are both anonymous (no information about the readers is collected) and likely to be an underestimate given the permissions to share and adapt the material. No information on the number of printed copies sold is provided. With that caveat in mind, it is nonetheless possible to state that the 12 volumes published between 2016 and 2022 had more than 1.3 million downloads combined. These downloads are not evenly distributed across the 12 published volumes, with just over 600,000 downloads associated with the three volumes described in this case (more details below).

While it is not possible to estimate the proportion of downloads were from readers within academia, the overall footprint of the book series is substantial. In order to explore the impact of the three SSBC in this case, we consider other sources such as the discussion of these volumes in popular media and their known use for executive education outside of academia.

Impact on education - *Introduction to Scientific Programming with Python (2020):* This book was written for a non-expert audience, requiring no prior programming experience and only basic mathematics (high-school level) as a prerequisite. It was originally written for use in entry level

university courses, but with the increasing general interest in programming it has reached a broader audience, as indicated by the 384 000 downloads since it was published in 2020. In addition to the download statistics, the reach of the book is suggested by the ratings on Amazon, with ratings and reviews from readers in Europe, the Americas, and South Asia. While the original target was university students, an important extension of Simula's education activities was launched in response to new requirements for programming as an integral part of the curriculum in the Norwegian school system. Introducing programming on all levels required a massive effort in continued education for teachers, which motivated the establishment of the *Simula CodeSchool*. The CodeSchool developed a series of courses for teaching teachers the basics of python which they could then implement in the classroom, and, as the need for digital competence training was prevalent throughout different occupations, Simula expanded these courses to target other employee groups. More than 2,000 continuing education participants completed courses in introductory python at the CodeSchool between its launch in 2018 and the end of the evaluation period.

Impact on national security discussions - *The Huawei and Snowden Questions (2018):* This book provides an excellent example of how the SSBC series' can be used to bring Simula's collective research expertise to bear in exploring difficult and complex problems facing society, and thereby help generate both consciousness raising and real political change.

According to the Springer statistics, this book has 164 000 registered downloads. This is likely an underrepresentation, given that it is also available for download from other major repositories such as OAPEN Library, Google Books and ResearchGate. The reach of this book is very likely more substantial than the download numbers indicate, as it gained attention in popular international media outlets and also initiated a number of discussions and investigations of Norwegian infrastructure security and vulnerability.

This volume explores how to investigate digital equipment that one does not trust, with the backdrop of the controversy surrounding Chinese providers of equipment to 5G networks in western countries. Based on this book the author, Professor Olav Lysne, was asked to frame a Norwegian policy on the matter, and the book was also distributed among several government agencies in other western countries, resulting in invitations for visits and further discussions. This volume is referred to as "a seminal book" in an opinion piece in the Harvard Business Review, a venue that reaches a broader audience of executives and decision makers than typical ICT research publications, bringing more attention to the dangers of procuring equipment that cannot be verified.

Impact on large-scale software project planning - *Time predictions* (2018): This final example shows how the SSBC series can impact decision making and planning in both the public and private sectors, by providing a solid research-based understanding of the challenges, risks and pitfalls when estimating a given project's timeline.

According to Springer's statistics, this book has over 71 000 downloads. Once again, this is likely an underrepresentation, as this book is available from mass retailers and distributors such as Amazon, OAPEN library, and EconBiz. *Time Predictions* is cited on numerous popular science blogs and web sites (see examples below), indicating a wide reach outside academia. One the authors, Magne Jørgensen, is part of an advisory board ("Digitaliseringsrådet") which gives advice to public institutions about ICT projects. This volume is also frequently used in courses for the ICT industry in Norway, especially as part of the HIT network (HIT: Hovedstadsområdets nettverk for IT-styring og ledelse), an active network those engaged in IT governance and leadership in Norway with over 600 members from the public and private sectors. This book helps decision makers as part of HIT and beyond to, as the subtitle says, understand and avoid unrealism in project planning and everyday life.

While each of the showcased books certainly have impact of their own, the most important observation for this impact case is that the SSBC book series has been successfully established as an efficient channel for dissemination of research-based knowledge to a wide audience, also beyond academia. By downloading the online version of the books, access to this knowledge is free of charge and available at the fingertips of a world-wide audience. Given the widespread access to internet, this can be seen as an important contribution to democratisation of knowledge and education, largely independent of economic, ethnic or cultural status. The SSBC editorial board welcomes future additions to the series that will further widen its impact beyond academia.

5. Sources to corroborate the impact

- All volumes of the Simula SpringerBriefs on Computing series and corresponding download statistics (called 'accesses') are available from Springer: www.springer.com/series/13548
- The CodeSchool's continuing education material for teaching basics of python can be accessed here: github.com/codeschool (note: all in Norwegian, due to the target audience).
- Media sources illustrating of the impact on national security discussions:
    - Harvard Business Review article (March 2019) hbr.org/2019/03/cybersecurity-is-putting-customer-trust-at-the-center-of-competition
    - Dagens Næringsliv (Feb 2019) www.dn.no/telekom/mobilnett/spionasje/huawei/anbefaler-flere-leverandorer-for-a-hindre-spionasje/2-1-546244
    - Teknologirådet (advisory board to the Norwegian government, Apr 2019) teknologiradet.no/5g-blir-supert-og-sarbart/
    - The North Atlantic Committee's weekly analysis: www.atlanterhavskomiteen.no/ukens-analyse/huawei-og-geopolitiseringen-av-teknologi
- Media sources indicating the impact on project planning and time estimations:
    - medium.com/@mobilab/estimations-predicting-small-parts-of-the-future-part-2-afa8909e2511
    - codebots.com/way-of-working/what-is-a-product-backlog
    - www.qualicen.de/requirements-engineering-and-origami/

Institution: SINTEF Energy Research
Administrative unit: SINTEF Energy Research
Title of case study: Enabling low-pressure transport of CO_2 by ships
Period when the underpinning research was undertaken: 2011-2021
Period when staff involved in the underpinning research were employed by the submitting institution: 2011-ongoing
Period when the impact occurred: 2011 - ongoing

1. Summary of the impact

With the rise of shipping as a key enabling technology for CO_2 capture and storage (CCS), the question of at which pressure the CO_2 should be transported has risen over the past decade. To identify the optimal transport pressure, SINTEF Energy Research have developed a suite of models for CO_2 liquefaction and transport by ship. Based on this, low-pressure transport has been identified as the most cost-efficient strategy, and that it could enable a large cost-reduction thus impacting the economic viability of the whole CCS value chain. Experimental work has been performed to validate the thermodynamic properties and conditions at which the CO_2 is efficiently liquefied. Industrial actors are now looking to implement low pressure shipping solution to the market.

2. Underpinning research

To identify the optimal transport pressure, SINTEF Energy Research have developed a suite of models for CO_2 liquefaction and transport via ship. This suite of models is part of the iCCS tool developed by SINTEF Energy Research for techno-economic and environmental evaluation of CCS value chains. The research work has consisted of building advanced process models of CO_2 liquefaction processes and CO_2 transport relying on past and ongoing research, both experimental and numerical. This includes:

- Accurate phase equilibrium measurements of CO_2-rich mixtures enabled by the projects: CO2MIX - VLE (NO2.3) ECCSEL [7], and the Centres for Environment-friendly Energy Research (FME) BIGCCS and NCCS
- Advanced modelling capabilities on heat exchanger design through SINTEF Energy Research model FlexHX
- Advanced CCS process and value chain modelling of the iCCS tool, a tool for techno-economic and environmental evaluation of CCS value chains, built through the FMEs BIGCCS and NCCS

Based on this, transport of liquified CO_2 via ship has been modelled in detail and optimised. The research has concluded that low-pressure transport (~7bar) is the most cost-efficient strategy and could enable a large cost-reduction potential – as much as 30% of the CO_2 liquefaction and transportation cost compared to the commercially available mid pressure shipping.

However, industrial concerns have been raised about the risk associated with potential dry ice formation at such low-pressure, and a subsequent activity has also been to perform experimental work to understand this potential risk. This was done via an experimental campaign to de-risk and gain operational experience from the low-pressure CO_2 liquefaction process using the SEPPIL (NO2.4) ECCSEL rig [9]. These experiments demonstrate that pure CO_2 can be safely liquefied at 5.8 bar(a) and a CO_2/N_2 mixture can be liquefied at 6.5 bar(a) without issues related to dry ice formation. This has enabled a better understanding of the feasibility of the theoretically identified solutions.

This work has been performed as part of the FME centre NCCS in respectively, Task 1 "CCS value chain and legal aspects" and Task 4 "CO_2 capture and transport-conditioning through liquefaction", and draws on previous knowledge and models acquired through the following projects:

- EU portfolio: EUFP7 COCATE, EU FP7 IMPACTS [10], ACT ELEGANCY [11], EU FP7 CEMCAP
- FME BIGCCS SP4 CO_2 value chains, BIGCCS SP2 CO_2 transport [12], FME NCCS Task 7 CO_2 transport, and Task 8 Thermodynamics [13]
- KSP: CO2MIX
- ECCSEL ERIC [20] (SINTEF Energy Research was paramount in applying for, establish and operating the pan-European CCS research infrastructure): CO2MIX - VLE (NO2.3) [7], SEPPIL (NO2.4) ECCSEL [9], VISC-DENS (NO2.6) ECCSEL [8]

Key researchers:

- Simon Roussanaly, Research Scientist, SINTEF Energy Research (2011 – present)
- Han Deng, Research Scientist, SINTEF Energy Research (2017 – present)
- Geir Skaugen, Research Scientist, SINTEF Energy Research (1986 – present)
- Stian Trædal, Research Scientist, SINTEF Energy Research (2017 – 2023)
- Jacob Hans Georg Stang, Research Scientist, SINTEF Energy Research (1995 – present)
- Ingrid Snustad, Research Scientist, SINTEF Energy Research (2013 – present)
- Martin Viktor Johansson, Research Scientist, SINTEF Energy Research (2020 – 2022)
- David Berstad, Research Scientist, SINTEF Energy Research (2008 – present)
- Sigurd Weidemann Løvseth, Senior Research Scientist, SINTEF Energy Research (2009 – 2023)
- Morten Hammer, Research Scientist, SINTEF Energy Research (2011 – present)
- Svend Tollak Munkejord, Chief Scientist, SINTEF Energy Research (1998 – present)

3. References to the research (indicative maximum of six references)

[1] Roussanaly, Simon, et al. 2021 At what Pressure Shall CO_2 Be Transported by Ship? An in-Depth Cost Comparison of 7 and 15 Barg Shipping. Energies 14.18: 5635.
https://doi.org/10.3390/en14185635

[2] Deng H., Roussanaly S., Skaugen G., 2019. Techno-economic analyses of CO_2 liquefaction: Impact of product pressure and impurities. International journal of refrigeration 103, 301-315.
https://doi.org/10.1016/j.ijrefrig.2019.04.011

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https://hdl.handle.net/11250/2984247

[4] Bjerketvedt, Vegard Skonseng; Tomasgard, Asgeir; Roussanaly, Simon. Deploying a shipping infrastructure to enable carbon capture and storage from Norwegian industries. Journal of Cleaner Production 2021
https://doi.org/10.1016/j.jclepro.2021.129586

[5] Løvseth, Sigurd W., et al. 2018. Thermodynamics of the carbon dioxide plus argon (CO_2 + Ar) system: An improved reference mixture model and measurements of vapor-liquid, vapor-solid, liquid-solid and vapor-liquid-solid phase equilibrium data at the temperatures 213–299 K and pressures up to 16 MPa. Fluid Phase Equilibria 466, 46-78.
http://hdl.handle.net/11250/2495336

[6] Munkejord, Svend Tollak; Hammer, Morten; Løvseth, Sigurd W.2016. CO_2 transport: Data and models – A review. Applied Energy 169, 499-523.
https://doi.org/10.1016/j.apenergy.2016.01.100

4. Details of the impact

Pipeline has historically been the preferred means of transporting CO_2 due to its low cost for short distances and opportunities for economies of scale. However, interest in ship-based transport of CO_2 for large-scale deployment of CCS has been growing in the past decade. Shipping in particular present the following advantages: being a flexible and cost-effective solution for transporting CO_2 over long distances and in small volumes, requiring low capital investment, and involving opportunities for co-utilisation of infrastructure.

In recent years, questions have been raised regarding optimal transport conditions for CO_2. While 15 bar is currently the best pressure for CO_2 transport in Norway, it is thought that lower pressure-based transport could be a better solution in the future. However, no open-access study previous to our research had satisfactorily concluded on the optimal transport conditions for CO_2 from a CCS perspective.

In order to fill this knowledge gap, SINTEF Energy Research has developed a suite of models, as part of its iCCS tool, to identify optimal conditions for transporting CO_2 by ship. This work was performed as part of the "CO_2 value chain and legal aspects" task in the Norwegian CCS Research Centre (NCCS) – which is also led by SINTEF Energy Research [2]. The model has been used to identify instances where transporting CO_2 at low pressures could be more cost efficient than medium pressures, which is the current standard, as well as identify the potential cost reductions. Overall, transporting CO_2 at a pressure of 7 bar instead of 15 bar could reduce costs by at least 15% for a wide range of volumes and distances, and 30% for most of the relevant cases (i.e., excluding cases where pipeline would be the preferred mean of transportation). Furthermore, reductions greater than 30% can be achieved for distances of about 1000 km and larger, which are the relevant conditions for transport of CO_2 between mainland Europe and Norway. Such reductions are also significant in terms of absolute CO_2 conditioning and transport costs, as for distances greater than 350 and 1000 km, the 7 barg shipping option results in costs of at least 5 and 10 €/tCO_2, respectively, lower than for the 15 barg option. Our research has also confirmed these conclusions even if the CO_2 contained significant level of impurities and while considering the uncertainty of the capital costs of ships.[1]

While these results demonstrated the potential and importance to enable low-pressure shipping, another important aspect has been to verify their feasibility through experimental research. The experimental activities performed in NCCS Task 4 "CO_2 capture and transport-conditioning through liquefaction" have further strengthened the confidence in the feasibility of low-pressure CO_2 shipping. The risk associated with dry ice formation has been a major concern preventing industry to move towards low-pressure shipping. These concerns have been addressed and mitigated by our experimental demonstrations.

The newly commissioned FASafe (NO2.9) ECCSEL rig [14], operated by SINTEF Energy Research, will enable further de-risking of ship-based CO_2 transport operations by providing necessary experimental data and validation of flow-assurance mechanisms and tools. Similarly, the newly granted Knowledge-building Project (KSP) CO2FFER [15] will partially build on this knowledge to provide key models and experimental data to support the optimisation and further development of CO_2 ship transport and direct CO_2 injection from ships.

The results from our research, both through modelling and experimental work, have been instrumental in supporting industry towards transitioning towards low-pressure in the coming few years. Several actors, such as Altera infrastructure are now looking to implement low-pressure based shipping and receiving facilities for CO_2 transport [17]. This solution is now also considered as part of CCS value chain development of Norwegian and European actors (CCS Midt-Norge [18], CCS Haugalandet [19], ACCSESS). Finally, unlocking cost-efficient CO_2 transport is also key in enabling Norway as a CO_2 storage provide for Europe considering the otherwise high transport cost resulting of the distance between Norway and continental Europe.

5. Sources to corroborate the impact

[7] https://www.eccsel.org/catalogue/112

[8] https://www.eccsel.org/catalogue/116

[9] https://eccsel.org/catalogue/90

[10] https://www.sintef.no/en/projects/2013/impacts-the-impact-of-the-quality-of-co2-on-transp/results/publications-and-dissemination/#menu

[11] https://www.sintef.no/en/projects/2017/elegancy-enabling-a-low-carbon-economy-via-hydrogen-and-ccs/programme/

[12] https://www.sintef.no/prosjekter/2009/bigccs-international-ccs-research-centre/

[13] https://nccs.no/

[14] https://www.eccsel.org/catalogue/306

[15] https://www.sintef.no/en/projects/2023/co2ffer-data-and-models-to-optimise-maritime-co2-transport-and-offshore-injection/

[16] https://nccs.no/innovation/low-pressure-co2-transport-by-ships/

[17] General-presentation-2023-Stella-Maris-CCS.pdf (alterainfra.com)

[18] ccs-midt-norge-final-report-v1.0---signert.pdf (sintef.no)

[19] SINTEF Open: CCS Haugalandet : Evaluation of CO2 logistics scenarios in the Haugalandet region (unit.no)

[20] https://www.eccsel.org/catalogue/169

Institution: SINTEF Energy Research
Administrative unit: SINTEF Energy Research
Title of case study: SHOP – short-term planning of hydropower production
Period when the underpinning research was undertaken: 1989-ongoing
Period when staff involved in the underpinning research were employed by the submitting institution: 1989-ongoing
Period when the impact occurred: 2003-ongoing

1. Summary of the impact

SHOP is a software tool with advanced algorithms that develops detailed production plans based on inflow, market price, and load information.

SHOP helps power producers to optimize operations and maximize the value of production. The software enables customers to achieve a 2% increase in the value of hydroelectric power production through optimal production and flow in the watercourses. The increased value is based on information provided by the power producers, and the estimated financial gain over the past ten years amounts to NOK 6.8 billion.

2. Underpinning research (indicative maximum 500 words)

Both topography and climate have made Norway one of the world's leading hydropower countries. Hydropower accounts for more than 95% of the total electricity production in Norway. In such a hydro-dominated power system, hydro scheduling optimization tools are of critical importance to the efficient use of hydro resources, for which even a tiny increase in the energy conversion efficiency matters.

SINTEF Energy Research has more than 50 years of experience in developing hydro scheduling tools that cover long-, mid- and short-term planning problems. The upcoming deregulation process of the Norwegian power system at the end of the 1980s boosted the research interest in short-term hydro scheduling (STHS). The state-owned power and grid company Statkraftverkene financed the initial prototype of SHOP in 1989.

The first operational version was delivered in 1996 to Harris Controls who licensed SHOP to hydropower producers in India and Egypt. Further research on algorithm development, the breakthrough of computer hardware, and result validation supported by the industry led to the first operational use of SHOP in Norway at Statkraft in 2003. Since then, SHOP has been taken into use by more than 25 major hydropower producers in Norway, Sweden, Switzerland, Italy, Austria, and Chile. At the same time, SHOP has facilitated numerous research projects on hydro scheduling. To keep SHOP state-of-the-art, the problem formulation, solution methods, and data input structure were redesigned in 1996, 2008, and 2016, respectively.

SHOP considers complex watercourses with various strategic, physical, technical and market constraints. In addition to the common plant module for energy generation and reservoir module for water management, it also comprises the gate, junction, reserve, simulation, bidding, and uncertainty modules that are consistent with the real-world hydro system and market conditions. Different functionalities have been developed to meet the requirements posed from the real-life operation.

Key researchers:

- Olav Bjarte Fosso, Research Scientist, SINTEF Energy Research (1989 - 2002, part-time advisor from 2002)
- Michael Martin Belsnes, Research Scientist, SINTEF Energy Research (1995 - present)
- Hans Ivar Skjelbred, Research Scientist, SINTEF Energy Research (2003 - present)
- Ellen Krohn Aasgård, Research Scientist, SINTEF Energy Research (2013 - 2022)

- Jiehong Kong, Research Scientist, SINTEF Energy Research (2013 - present)
- Christian Øyn Naversen, Research Scientist, SINTEF Energy Research (2015 - present)
- Per Aaslid, Research Scientist, SINTEF Energy Research (2015 - present)

3. References to the research

[1] Skjelbred, Hans Ivar; Kong, Jiehong; Aasgård, Ellen Krohn; Belsnes, Michael Martin; Fosso, Olav Bjarte., Algorithmic Development and Industrial Applications of Short-term Hydro Scheduling in the Nordic Power Market. I: 2022 14th IEEE PES Asia Pacific Power & Energy Engineering Conference - APPEEC. IEEE (Institute of Electrical and Electronics Engineers) 2022 ISBN 978-1-6654-6738- https://doi.org/10.1109/appeec53445.2022.10072168

[2] Kong, Jiehong; Skjelbred, Hans Ivar; Fosso, Olav B. An overview on formulations and optimization methods for the unit-based short-term hydro scheduling problem. Electric power systems research 2019 ;Volum 178. s. 1-14
http://hdl.handle.net/11250/2620238

[3] Aasgård, Ellen Krohn; Skjelbred, Hans Ivar, Progressive hedging for stochastic programs with cross-scenario inequality constraints. Computational Management Science 2019; Volum 17.(1) s. 141-160
https://doi.org/10.1007/s10287-019-00359-z

[4] Aaslid, Per; Skjelbred, Hans Ivar; Bale, Sigri Scott., Modelling Tunnel Network Flow and Minimum Pressure Height in Short-Term Hydropower Scheduling. I: Proceedings of the 6th International Workshop on Hydro Scheduling in Competitive Electricity Markets. Springer Nature 2019 ISBN 978-3-030-03311-8. s. 62-68
https://doi.org/10.1007/978-3-030-03311-8_8

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http://dx.doi.org/10.1109/APPEEC53445.2022.10072120

[6] Skjelbred, Hans Ivar; Kong, Jiehong; Larsen, Tellef Juell; Kristiansen, Fredd., Operational use of marginal cost curves for hydropower plants as decision support in real-time balancing markets. Proceedings of the 14th International Conference on the European Energy Market 2017 (EEM)
http://dx.doi.org/10.1109/EEM.2017.7981875

4. Details of the impact

According to a study by Impello and Menon Economics from 2018, SHOP has enabled customers to achieve a 2% increase in the value of hydroelectric power production through optimal production and flow in the watercourses. The increased value is based on information provided by the power producers, and the estimated financial gain over a ten-year period (2008-2017) amounts to NOK 6.8 billion. According to these calculations, an additional NOK 13.7 billion can be realized if all Nordic hydropower producers adopt SHOP and similar effects can be expected for other European producers.

SHOP (Short-term Hydro Optimization Program) is a modelling tool for short-term hydro operation planning. The program considers complex watercourses with various strategic, physical, technical and market constraints. Different functionalities have been developed to meet the requirements posed from the real-life operation, such as the gate, junction, reserve, simulation, bidding, and uncertainty modules. SHOP is coded in the C/C++ programming language. The optimization problem can be solved by commercial solvers CPLEX and GUROBI or open-source solvers like CBC. The

optimization process is designed to be carried out either locally, on an in-house server, or in cloud services.

The general objective of the program is to utilize the available resources and to maximize the profit within the period in consideration by exploiting the options for buying and selling in the spot market while fulfilling firm load obligations. SINTEF Energy Research and NTNU have developed the program through an extensive collaboration with the power industry in Norway. The first operational version was delivered in 1996 and has since been improved to consider more details of the production system, changing market conditions due to the introduction of intermittent renewables and new climate variations.

SHOP assists power plants in planning their production over a one to two-week time horizon. Here, the production systems are complex. The reservoirs are interconnected through rivers and tunnel systems, allowing water to generate electricity in multiple power stations as it flows towards the lowlands. SHOP ensures that power plants can produce as much as possible when the demand is high. The process ensures that the upper reservoirs are sufficiently filled when forecasts indicate high electricity demand. However, more is needed to maximize production capacity. In such situations, SHOP advises how far the water level should be lowered in the lower reservoirs to utilize the greatest possible drop height.

When electricity prices are low, SHOP ensures that power plants can meet their production obligations at the lowest possible cost. This means producing electricity with as little water consumption as possible. The most significant operating cost in the hydropower industry is, in fact, the future revenues that the power plant misses out on for every litre of used water that could have been utilized in later periods with higher power demand. For operators, it is impossible to arrange these configurations optimally. This involves countless variables and sizes, ranging from the physical properties of the waterways between the uppermost reservoir and the lowest power station to questions about how efficiently each turbine will operate with more or less water. SHOP handles all this through advanced mathematical processing of data about inflow, market prices, and production technical conditions.

SHOP does not only contribute to mitigating the adverse effects of energy production by enabling the transition to renewable sources, but it also ensures that hydropower production does not adversely affect the local environment in and around the watercourses. Minimum flow restrictions and other environmental aspects are included in SHOP to protect freshwater ecosystems and use of the river for other purposes.

Collaboration with Statkraft and other industry partners has been crucial in the development process. SINTEF Energy Research and NTNU have developed methods and tools that are now widely used among hydropower producers in the Nordic countries, Switzerland, Italy, Austria and Chile. For the users, SHOP forms an integrated, business-critical part of operations. At present SHOP is used on a daily basis to optimize more than 60.000 MW of hydropower, representing an annual generation of more than 150 TWh. This corresponds to 28% of the installed capacity in Europe. The development of SHOP is enabled through industrial financed projects and programs administered by the Research Council of Norway such as RENERGI, ENERGIX, FME Cedren and FME HydroCen.

5. Sources to corroborate the impact

[7] https://www.sintef.no/en/expertise/sintef-energy-research/digitalization-of-hydropower/
[8] https://www.sintef.no/en/sintef-research-areas/hydropower/hydropower-production-planning/
[9] https://www.sintef.no/en/sintef-research-areas/hydropower/ou-upgrading-and-expanding-hydropower/
[10] https://blog.sintef.com/sintefenergy/shop-hydropower-scheduling-creates-value/

Institution: SINTEF Energy Research
Administrative unit: SINTEF Energy Research
Title of case study: Use of natural refrigerants in refrigeration and heat pumping systems
Period when the underpinning research was undertaken: 1990-2024
Period when staff involved in the underpinning research were employed by the submitting institution: 1985-2024
Period when the impact occurred: 2012-2022

1. Summary of the impact

Research on developing integrated cooling, heating, and ventilation systems for supermarkets and high-temperature industrial heat pumps started as early as 1990 and has progressed significantly, especially under FME HighEFF. Data from HighEFF show that installed systems for supermarkets have resulted in yearly reductions of more than 37 million metric tonnes of CO_2 eq emissions, related to 30-35% higher energy efficiency and avoidance of HFC emissions. Systems for industrial refrigeration and electric heat pumps based on based on natural refrigerants that may replace use of fossil fuels have also been implemented in other industries. Market demand to satisfy the goals in the Paris Agreement, corresponds to several hundred of MW installed capacity per month in the coming 10 years.

2. Underpinning research

The research performed is mainly within Mechanical Engineering, covering scientific disciplines within Process technology, Refrigeration engineering, Thermodynamics and Fluid flow.

Significant contributions have been the basis for groundbreaking developments, primarily for use of CO_2 as refrigeration, but over the last years more broadly covering all natural refrigerants, namely CO_2, NH_3, Hydrocarbons, water and their mixtures. The latter four for applications where these are better suited than CO_2. Research has been performed on all levels from more fundamental research related to fluid flow and heat transfer, on a component level for heat exchangers, compressors and components for work recovery such as ejectors and expanders, as well as for systems developments and implementation in various applications. Especially for CO_2 as refrigerant, this has required groundbreaking development due to the thermodynamic differences from other typical refrigerants, e.g., exemplified by the much higher operating pressures of up to 150 bar and the need to operate in a transcritical cycle.

SINTEF Energy Research and NTNU started development of refrigeration, air conditioning and heat pump systems based on use of natural refrigerants in late 1980s, to replace CFCs, HCFCs and HFCs. These are fluids being either ozone depleting or strong greenhouse gases. The core of the development was on using CO_2 as refrigerant, especially in supermarkets and heat pumps.

In FME HighEFF (2017-2024) the development of integrated cooling, heating and ventilation systems in supermarkets has continued. Further, systems for industrial refrigeration have been developed based on natural refrigerants for Norsk Kylling, and likewise for high temperature heat pumps in the industry which replace use of fossil fuels for Tine Meieri in Bergen. The same knowledge has also contributed to development of heat to power systems, enabling electricity production from surplus heat in the industry.

The importance of the development is also reflected in the new EU F-gas directive, the REACH PFAS proposal and the importance heat pumps are expected to play in the coming decarbonization. Globally

pin-pointed needs of development from COP28 in Dubai in 2023 (UN Conference of the Parties), on improved efficiency cooling systems (Global Cooling Pledge), need for energy efficiency improvements (Renewables and energy efficiency Pledge) and the final First Global Stocktake, underpins the need for action.

Key researchers

- Krzystof Banasiak, Senior Research Scientist, SINTEF Energy Research (2013 – Present)
- Armin Hafner, Senior Research Scientist, SINTEF Energy Research (1997 – 2015), currently Professor at NTNU
- Michael Bantle, Senior Research Scientist, SINTEF Energy Research (2011-2022), currently CTO Aneo Industry
- Trond Andresen, Senior Research Scientist, SINTEF Energy Research (2003 – Present)
- Petter Nekså, Chief Scientist, SINTEF Energy Research (1985 – Present)

3. References to the research (indicative maximum of six references)

[1] Hafner, Armin; Poppi, Stefano; Nekså, Petter; Minetto, Silvia; Eikevik, Trygve Magne. Development of Commersial Refrigeration Systems with Heat Recovery for Supermaket Buildings. I: Proceedings of 10th IIR Gustav Lorentzen Conference, June 25 - 27 2012 Delft, the Netherlands. International Institute of Refrigeration 2012 ISBN 978-2-913149-90-8. s.

[2] Kus, Bartosz; Nekså, Petter. (2013): Oil free turbo-compressors for CO_2 refrigeration applications. Int j of refrigeration 2013 ; Volum 36.(5) s. 1576-1583
http://dx.doi.org/10.1016/j.ijrefrig.2013.03.002

[3] Nekså, Petter; Hafner, Armin; Bredesen, Arne Mathias; Eikevik, Trygve Magne. CO_2 as working fluid - technological development on the road to sustainable refrigeration. I: 12th IIR Gustav Lorentzen Conference on Natural Refrigerants GL2016 : Proceedings. International Institute of Refrigeration 2016 ISBN 9782362150180
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[4] Bamigbetan, Opeyemi Olayinka; Eikevik, Trygve Magne; Nekså, Petter; Bantle, Michael. Review of Vapour Compression Heat Pumps for High Temperature Heating using Natural Working Fluids. International journal of refrigeration 2017 ;Volum 80. s. 197-211
http://hdl.handle.net/11250/2487406

[5] Gullo, Paride; Hafner, Armin; Banasiak, Krzysztof; Minetto, Silvia; Kriezi, Ekaterini; Multi-Ejector Concept: A Comprehensive Review on its Latest Technological Developments, Journal of Energies, January 2019
http://hdl.handle.net/11250/2582890

[6] Singh, S; Maiya, PM; Hafner, A; Banasiak, K; Neksa, P, Energy efficient multiejector CO_2 cooling system for high ambient temperature, Thermal Science and Eng Progress, 2020, Vol 19,
https://dx.doi.org/10.1016/j.tsep.2020.100590

4. Details of the impact

Closed-circuit heat pumping systems, like refrigeration, air conditioning systems, and heat pumps are essential to control temperatures in hot and cold environments. These systems require working fluids to extract heat from one source and transfer it to another at a higher temperature level. An ever-growing population with rising living standards will increase the use of refrigerators and heat pumps to heat or cool homes and workplaces, as well as in the industry. A large part of the potential is found in developing countries where HFCs are dominant, and transitioning to more long-term and sustainable solutions will have a significant climate effect. Studies have shown that if cooling and heating systems that use HFCs today switch to CO_2 and new systems exclusively use CO_2 or other natural refrigerants, we can avoid global warming by half a degree.

Since the 1990s, industries have used hydrofluorocarbons (HFCs) as a working medium due to their lack of ozone-depleting properties. However, research has shown that HFCs, despite their initial appeal, are potent greenhouse gases that significantly contribute to global warming. In January 2019, the Kigali Amendment to the -Montreal Protocol entered into force, which will phase down the use of HFCs.

SINTEF Energy Research and NTNU has conducted significant work on -natural working fluids (NWF) over 30 years. Retired NTH Professor Emeritus Gustav Lorentzen was the figurehead behind the research, first proposing CO_2 as a refrigerant in 1987. Through his leadership, Norwegian research began to collaborate closely with Norsk Hydro, which needed alternative refrigeration systems for their aluminium products. In the later years, SINTEF Energy Research has also had an extensive collaboration with NTNU to support an agile adoption of natural refrigerants in heat pumps and refrigeration systems for the maritime sector.

Another industry that needs to replace HFCs is supermarkets. Commercial refrigeration systems mainly use synthetic substances like HCFCs and HFCs as refrigerants. Impello and Menon Economics conducted a study on the effect from investments in R&D on environmentally friendly energy between 2008 and 2017 where projects conducted by SINTEF Energy Research on CO_2-based cooling and heat pump systems for supermarkets were included [7]. The study identifies several effects in supermarkets that have applied the technology. An average supermarket releases more than 20% of its refrigerant charge each year, which leads to an emission of roughly 50 tons of CO_2 equivalents. The Impello/Menon study concluded that eighteen thousand supermarkets worldwide already had adopted CO_2 as a refrigerant, and that the trend is expanding quickly in number and geographic reach. The shift has resulted in a significant environmental impact, achieving an annual reduction of 19 million metric tons of CO_2 equivalent emissions by removing greenhouse gases from refrigeration systems and reduced energy consumption in the period of the study. In terms of energy savings, there was a notable reduction of 1.6 terawatt-hours per year, which translates to 30% less energy used. Financially, this translates into an annual saving of 650 million NOK in energy costs, directly benefiting the owners of buildings and stores. The Norwegian supermarkets represented about 15% of these overall figures.

The study highlights a substantial opportunity for energy savings in European supermarkets, noting that they could decrease energy usage by 9 terawatt-hours annually. This reduction in energy consumption is projected to significantly reduce emissions, cutting annual CO_2 equivalent emissions by 53 million metric tons. The current installed base is about 80 000 supermarkets [13].

Figures recently confirmed by readings from REMA1000 supermarkets in Norway and Scandinavia, showing an average saving of 35% in the 95 stores where the technology has been implemented, summing up to 18 GWh/yr which is comparable to the annual energy consumption from 1200 households.

As part of the SuperSmart project [8], funded by the European Union, researchers from SINTEF Energy Research and other European organizations worked on addressing the challenges of transitioning to new refrigerants. The project highlighted the importance of increasing awareness and knowledge about the new solutions to ensure their successful adoption. The project's findings are being applied in the European market, and the impact is extended through international projects in India and other countries.

ENERGIX and the industry have co-founded research activities in the last ten years, including IPN and KPN. Since 2017, FME HighEFF has been central in the research.

5. Sources to corroborate the impact (indicative maximum of ten references)

[7]https://www.regjeringen.no/contentassets/816c63dcb0ea49768ec03cd64828af5a/effekter_av_energiforskningen.pdf

[8] https://blog.sintef.com/sintefenergy/energy-efficiency/supersmart-we-work-towards-an-european-ecolabel-for-supermarkets/

[9] https://blog.sintef.com/sintefenergy/energy-efficiency/keeping-ice-cream-cold-doesnt-have-to-harm-the-environment/

[10] https://blog.sintef.com/sintefenergy/energy-efficiency/heat-pumps-and-refrigeration-systems-on-board-naturally/

[11] https://blog.sintef.com/sintefenergy/energy-efficiency/cold-thermal-energy-storage/

[12] https://www.hybridenergy.no/referenceplants/tine-bergen-norway/

[13] https://atmosphere.cool/atmo-market-report-2023/

Institution: SINTEF Energy Research
Administrative unit: SINTEF Energy Research
Title of case study: Cost-effective energy storage systems
Period when the underpinning research was undertaken: 2017-2023
Period when staff involved in the underpinning research were employed by the submitting institution: 2017-2023
Period when the impact occurred: 2021-ongoing

1. Summary of the impact

Compared to other methods that store heat, Phase Change Materials make thermal storage units more compact and can operate on a narrow temperature range. This makes it possible to store large amounts of thermal energy from hot or cold flows, only a few degrees above or below the operating temperature. SINTEF Energy Research and NTNU have developed technology that use efficient PCMs for both cooling and heating purposes. The use of this technology can reduce energy consumption and energy costs in a wide range of industries.

2. Underpinning research

Our research on PCM was initiated in 2017 in a three-year project with public basic funding at SINTEF Energy Research. The goal was to establish a knowledge base for user-driven research in the continuation. The research within this initial project (PCM-EFF) included aspects related to suitable materials for the thermal energy storage, including material characterization, smart system control for efficient operation in an energy system, mapping state of charge for the thermal storage, phase changing processes etc. In parallel with PCM-EFF, related topics more directed for industrial applications of PCM were developed within the 8-year Centre of Excellence FME HighEFF, starting also in 2017, with a dedicated work package for thermal energy storage for increased energy efficiency in industry. R&D topics of particular relevance was to reduce peak loads in industrial operations. Another key R&D project was KSP PCM-STORE (2021-2025), financed by the Research Council of Norway and industry partners, which focused on further developing the technology towards low- and medium-temperature storage for the industry. For demonstration of PCM in realistic operations a pilot was developed and finally installed in 2021 at the ZEB Laboratory at the Gløshaugen campus, a pilot that now has been in operation for more than two years. Operational experience from this pilot has also benefited from digital system control allowing for virtual monitoring and operation. As such, digitalization has also been an important R&D area for this application. Following the development in the internal projects, the user driven R&D projects and the pilot – the company Cartesian was formed in 2023 as a spin-off company commercializing the technology.

Key researchers

- Alexis Sevault, Research Scientist, SINTEF Energy Research (2012 – 2022), joined the spin-off company Cartesian as CTO in 2023
- Håkon Selvnes, PhD student NTNU (2017 – 2021), Research Scientist, SINTEF Energy Research 2021-2023, joined the spin-off company Cartesian in 2023
- Jorge Salgado Beceiro, Research Manager, SINTEF Energy Research (2022 – present)
- Magnus Rotan, Research Scientist, SINTEF Energy Research (2021 – present), Post Doc/Researcher NTNU (2017-2021)
- Olav Galteland, Research Scientist, SINTEF Energy Research (2022 – present)
- Ragnhild Sæterli, Research Scientist, SINTEF Energy Research (2020 – present)

3. References to the research

[1] Sevault, Alexis; Kauko, Hanne; Bugge, Mette; Banasiak, Krzysztof; Haugen, Nils Erland L; Skreiberg, Øyvind. Phase change materials for thermal energy storage in low- and high-temperature applications: a state-of-the-art. SINTEF Energy Research Report 2017 https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/2487493

[2] Sevault, Alexis; Soibam, Jerol; Haugen, Nils Erland L.; Skreiberg, Øyvind. Investigation of an Innovative Latent Heat Storage Concept in a Stovepipe. Chemical engineering transactions", vol 65, 2018 https://www.aidic.it/iconbm2018/programma/3sevault.pdf

[3] Sevault, Alexis; Banasiak, Krzysztof; Bakken, Jørn; Hafner. Armin. A novel PCM accumulator for refrigerated display cabinet: design and CFD simulations. 12th IIR Conference on Phase-Change Materials and Slurries for Refrigeration and Air Conditioning (PCM 2018) https://www.researchgate.net/publication/323734651_A_novel_PCM_accumulator_for_refrigerated_display_cabinet_design_and_CFD_simulations

[4] Håkon Selvnes. Development of cold thermal energy storage for industrial refrigeration applications. PhD thesis NTNU 2022. https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/3034475

[5] Sevault, Alexis; Vullum-Bruer, Fride; Tranås, Olaf Lehn. Active PCM-Based Thermal Energy Storage in Buildings.Encyclopedia of Energy Storage: Volume 1-4, Pages 453 – 469, January 2022. https://www.scopus.com/record/display.uri?eid=2-s2.0-85151651396&origin=resultslist

4. Details of the impact

Phase-change materials (PCMs) are substances that absorb and release thermal energy during melting and freezing (phase change). When a PCM changes from solid to liquid or vice versa, it can store and release large amounts of energy at a relatively constant temperature. For example, the heat of fusion for water at 0 °C is 80 times larger than the heat you need to warm up liquid water by 1 degree Celsius.

The properties of PCMs make them useful in various applications, particularly in thermal energy storage systems to help optimize and reduce energy consumption. Ideally, the goal is to store heat or cold, similarly to how we store electrical energy in batteries, using charging and discharging phases.

PCMs can help maintain a stable temperature environment. When the surrounding temperature increases, the PCM absorbs heat and melts, and when the temperature decreases, the PCM releases heat and solidifies. Research conducted in FME HighEFF and KSP PCM-STORE on phase change materials (PCMs) in deep-freezing processes in the Norwegian food processing industry, indicate that using PCMs can halve the maximum power demand, leading to cost savings through installing smaller compressors and reduced energy use per ton of frozen product. Another expanding use of PCMs is in Concentrated Solar Plants (CSP), where they store heat at over 400°C during sunny hours for later heating use. The ongoing deployment of commercial large-scale heat storage solutions demonstrates the wide-ranging potential of PCMs across various industries.

SINTEF Energy Research (SER) and NTNU have, over the last decades, had substantial research on heat and cold storage. SER has conducted several projects on compact heat storage technology to help decarbonize buildings and industry processes. At the same time, NTNU has worked on finding

a compact solution to store cold energy for Norway's food processing industry. After several years of development, publishing, and proving the concept, they consolidated their work by demonstrating their findings into prototypes where they could use the same technology design for cold and heat storage. This collaboration resulted in the spin-out company "Cartesian", which will manufacture industrial solutions and products based on the complementary research done by SER and NTNU.

The company's first demo unit was installed in an office building in Trondheim, Norway, in 2021. The unit contains a bio-based wax phase change material with a melting temperature of 37°C. The thermal energy storage can be charged from various sources such as solar panels, heat pumps, or district heating and discharged to different systems like domestic hot water, radiators, ventilation, or heat pumps. Data collected over 14 months show that the total thermal energy capacity was 226 kWh, the average discharge rate was over 12.2 hours of 10.51 kW, and the average charge rate was over 11 hours of 13.7 kW. The average temperature reduction during storage was measured to 47.3 to 38 Celsius over 234 hours. The average heat loss was measured to be 64 W or 0.68% of the total daily capacity.

The main drivers for value creation from the Cartesian technology are:

1. Peak shaving – reducing cost of electricity and grid fees.
2. Load shifting – reducing energy cost and increasing the efficiency.
3. CAPEX reduction - reducing the required nominal output from the heating/cooling system.
4. OPEX reduction - increasing efficiency and lifetime for the heating/cooling system.

In establishing Cartesian, several areas were identified where the technology could play a pivotal role in Europe's energy transition:

- Transitioning from fossil fuels to renewable energy in local systems, particularly in industrial heat and steam production. Estimations show that Cartesian technology could reduce fossil fuel use by over 2 TWh and CO_2 emissions by 1 million tons. Its use in local building heating systems might have a greater impact, estimated at 20 TWh.
- Reducing energy consumption in heating and cooling systems, particularly those involving Carnot cycles. Cartesian technology could save about 30 TWh annually in Europe's commercial buildings.
- System-wide shift towards renewable energy, reducing emissions from fossil fuel-based power plants. This involves storing energy during periods of high renewable energy output and using it during high fossil fuel power demand, potentially cutting CO_2 emissions by tens of millions of tons, supported by a 260 GWh_{th} (GWh thermal energy) storage capacity in European heating and cooling systems.

5. Sources to corroborate the impact (indicative maximum of ten references)

[6] www.cartesian.no
[7] https://www.sintef.no/en/projects/pcm-eff/
[8] https://www.sintef.no/en/projects/woodcfd/
[9] https://www.sintef.no/en/projects/2020/pcm-store/
[10] https://www.sintef.no/en/projects/2021/pcm-stove/
[11] www.sintef.no/projectweb/higheff/annual-report-2017/saving-the-cold-for-later-decoupling-supply-and-demand/

Institution: SINTEF Energy Research
Administrative unit: SINTEF Energy Research
Title of case study: Grøft design – software enhancing the powergrid
Period when the underpinning research was undertaken: 2015-2023
Period when staff involved in the underpinning research were employed by the submitting institution: 2015-2023
Period when the impact occurred: 2019-2023

1. Summary of the impact

Grøft Design addresses the evolving power grid's shift towards sustainable, renewable energy, overcoming conventional and conservative methods that hinder infrastructure use and grid security. Developed in a collaboration between SINTEF Energy Research, REN and other industry partners, marks a significant change in how utilities determine power cable transmission capacity, enhancing energy production and consumption dynamics. This software can potentially improve Norwegian power cable transmission capacity by 5-20%, yielding a financial impact of 0.5 to 2 billion NOK. Its industry adoption and proven effectiveness in collaborative projects highlight its pivotal role in advancing Norway's energy infrastructure.

2. Underpinning research

In two IPN projects, computationally efficient finite element models and the methodology to generate such models based on input in a graphical user interface have been developed for high voltage cables. A major result is the simplified model for cables located in pipes which is crucial for Grøft Design, as published in IEEE Transactions of Power Delivery [4]. A method for implementing power cables with segmented conductors, important for electrification, in Grøft Design is described in [2]. The path of implementing novel research results into a commercial product (software) is published in [1, 5]. To use the models to determine transmission capacity for cables in service (being a critical infrastructure), they must be verified. Outside Trondheim, SINTEF Energy Research has developed a test site with a full-scale cable installation equipped with more than 300 sensors which has been used to verify models in Grøft Design, addressing typical “hot-spots" such as power cables crossing under roads – as explained in [6].

Correct thermal properties of the soil surrounding power cables are crucial for accurate determination of the transmission capacity. The ability to transport heat and critical temperatures for drying of soil and thermal run-away in power cables was studied for thermal backfill (natural and crushed rock sands) commonly used in Norway. This has provided important knowledge regarding which thermal backfills to use and critical temperatures for dryout [3] and methods to estimate thermal properties [7].

The research results from the two IPNs have provided a commercial software for transmission capacity calculations for power cables and new and important knowledge on thermal properties of soils, that is crucial in such capacity calculations. The software is now used daily by grid operators and engineering consultants in Norway.

This work has been performed in these projects partly funded by The Research Council of Norway:
IPN Økning i belastningsevnen til jordkabler, 2014-2018
IPN DynKap, 2019 – 2022

Key Researchers:

- Svein Magne Hellesø, Research Scientist, SINTEF Energy Research (2000 – present)
- Espen Eberg, Senior Research Scientist, SINTEF Energy Research (2011 – present)
- Henrik Strand, Research Scientist, SINTEF Energy Research (2019 – present)
- Kristian Thinn Solheim, Research Scientist, SINTEF Energy Research (2013 – present)

3. References to the research

[1] E. Eberg, S. M. Hellesø, H. Strand, M. Engebrethsen, and D. Østerberg, 'Implementation of Finite Element Analysis and Hybrid IEC-Models in Online Ampacity Tool' Jicable'23 - 11th International Conference on Power Insulated Cables: proceedings, 2023.

[2] H. Strand, E. Eberg, and G. J. Anders, 'Hybrid Method for Numerical Implementation of Segmented Power Cable Conductors in Finite-element Based Ampacity Calculation', *Proceedings of the Nordic Insulation Symposium*, vol. 27, no. 1, Art. no. 1, Jul. 2022, https://doi.org/10.5324/nordis.v27i1.4709

[3] K. Rieksts and E. Eberg, 'Experimental study on the effect of soil moisture content on critical temperature rise for typical cable backfill materials', *IEEE Transactions on Power Delivery*, pp. 1–12, 2022, https://doi.org/10.1109/TPWRD.2022.3220954

[4] S. M. Hellesø and E. Eberg, 'Simplified Model for Heat Transport for Cables in Pipes', *IEEE Transactions on Power Delivery*, vol. 37, no. 5, pp. 3813–3822, Oct. 2022 https://doi.org/10.1109/TPWRD.2021.3137876

[5] E. Eberg, K. Espeland, S. M. Hellesø, S. Hvidsten, and K. T. Solheim, 'Development of a web-based user-friendly cable ampacity calculation tool', in *CIRED Conference Proceedings*, Jun. 2019. https://doi.org/10.34890/964

[6] E. Eberg, K. Espeland, S. M. Hellesø, and S. Hvidsten, 'Full-scale case study of a road crossing thermal bottleneck in a buried medium-voltage cable installation', *CIRED - Open Access Proceedings Journal*, vol. 2017, no. 1, pp. 194–197, Oct. 2017 https://doi.org/10.1049/oap-cired.2017.0820

[7] K. Rieksts and E. Eberg, 'Estimation of the thermal resistivity of backfill materials using a practical approach', Jicable'19 - 10th International Conference on Power Insulated Cables: proceedings, 2019

4. Details of the impact

The power grid is undergoing a significant shift and has a key role in the transition to a sustainable climate-friendly society based on renewable, electrical energy - where production and consumption are larger and more dynamic than in today's grid. Examples of this are the introduction of new wind power and the electrification of transport on land and at sea. Existing static and conservative methods for calculating the transmission capacity in the cable network

hinders development and lead to unnecessary restrictions with regards to increasing the flexibility and dynamics in generation and consumption of electric power, to prevent effective utilization of existing infrastructure and reduce security of supply.

Grøft Design is a breakthrough in electrical infrastructure planning and design, addressing the complexities of the evolving power grid. Originating from a request for research by Norwegian utilities in 2015, the first version was introduced to the Norwegian market in 2019. The software replaces conventional methods for calculating transmission capacity, making calculation of hosting capacity of complex and realistic cable installations available to all cable owners, and not only scientists and cable manufacturers' in-house experts. This effectively removes a major hurdle for the utilization of existing infrastructure and compromising the security of supply. Grøft Design, with its innovative approach to the planning, design, and simulation of cable trenches, addresses these challenges head-on.

The software's capability to efficiently evaluate various design alternatives and confirm their viability through physical simulation has quickly made it the preferred solution for Norwegian distribution system operators and engineering consultants such as Norconsult and Multiconsult. The user-friendly graphical user interface allows for easy definition of the trench geometry, spatial constraints, and parameters such as cable type and number, and conflicting infrastructure. Thermal properties in the ground and weather conditions are considered, ensuring a comprehensive analysis. The software's integration of a component library, containing diverse cable types, pipes, concrete channels, and markings, further enhances its usefulness, allowing the user to define their own cable geometry.

SINTEF Energy Research has developed and validated the robust simulation models integrated in Grøft Design in partnership with industry stakeholders and REN – being a joint venture owned by and serving Norwegian grid companies. The partnership with REN has ensured a wide dissemination and availability in the market. The software also significantly advances the practical application of the research in optimizing transmission capacity that enhances the security of supply in regional grids.

The broader implications of Grøft Design's adoption resonate with global environmental objectives. The use can help catalyze the electrification of various sectors, thereby augmenting the penetration of renewable energy sources. This aligns with the overarching goals of the Paris Agreement and the UN's sustainability goals, aiming for a substantial reduction in greenhouse gas emissions. The research is also relevant for the transportation sector, where the use of Grøft Design can help optimize the electrification of land-based and maritime transport, yielding benefits such as reduced greenhouse gas emissions and diminished local air pollution, ultimately contributing positively to public health.

The use of Grøft Design has the potential to increase the available capacity in Norwegian power cable installations from 5 to 20% compared with existing practices, equating to a financial impact of 0.5 to 2 billion NOK. The software's adoption as the preferred solution in the Norwegian market underscores its industry validation and effectiveness. Additionally, collaborative projects with industry partners have practically demonstrated the software's capabilities, reinforcing its value and application in realistic scenarios.

The research is conducted through basic funding and collaborative projects in EnergiX/RCN.

5. Sources to corroborate the impact (indicative maximum of ten references)

[8] https://www.groftdesign.net/

[9] https://prosjektbanken.forskningsradet.no/en/project/FORISS/296215?Kilde=FORISS&distribution=Ar&chart=bar&calcType=funding&Sprak=no&sortBy=date&sortOrder=desc&resultCount=30&offset=0&Prosjektleder=Espen+Eberg

[10] https://www.energiforetagen.se/forlag/e-tjanster-webbshop/groft-design/

SINTEF Community, Case 1

Institution: SINTEF AS
Administrative unit: SINTEF Community
Title of case study: The SINTEF Building Research Design Guides- BFS
Period when the underpinning research was undertaken: 1997-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 1997- present
Period when the impact occurred: 2012-2022

1. Summary of Impact

The SINTEF Building Research Design Guides (BFS) is an outstanding and extensively used research dissemination tool that has had a long-term impact on the design quality of Norwegian buildings and building industry**.** BFS is a subscription-based and an on-line product.
The research results are implemented in form of guides in BFS as a practical benefit to the construction industry. The guidelines, solutions and recommendations ensure high quality in the planning, design and construction of buildings. The concise guidance on the principles and practicalities of construction is in conformity with the regulations to the building act (TEK) and has become a standard of quality. BFS is also used as a tool for educational purposes.

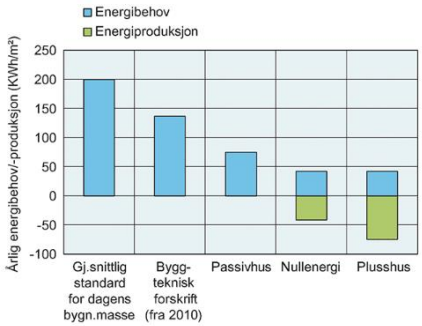
2. Underpinning research

Research conducted by SINTEF Community in collaboration with other partners, through various research projects have been incorporated into The SINTEF Building Research Design Guides (BFS). Some of the key research findings, recently implemented in BFS are presented below.

Zero Emission

The Research Centre on Zero Emission Buildings (ZEB, 2012-2017),

- New Zero Emission Buildings (ZEB) guidelines and calculation method, Guide 473.020 (2017). In 2017 there were no generally accepted definition of zero-emission buildings in Norway or internationally. The Norwegian research centre ZEB has defined various ambition levels for zero-emission buildings, which are described in this guide.
- Guide 473.003, Energy-efficient buildings (Dec 2015), provides overview of definitions which is used for various types of energy-efficient Buildings in Norway, in forms of concepts and definitions. The figure to the right shows an illustration of various building types and their need for energy and possibly energy production.



SFI Klima 2050, Climate Adaption (2015-2022):

There is a full list of SINTEF Building Design Guides based on research in SFI Klima 2050. An example is described:

- New revised guideline for the ventilation of pitched and nearly horizontal ventilated wooden roofs (525.101) based on a PhD-work by Gullbrekken, 2018.
  Local loss coefficients inside air cavity, wind pressure coefficients for roof venting purposes and air speed inside cavity as a function of outdoor wind speed was measured. A new model for necessary wind induced ventilation of air cavity to avoid melting of

snow was developed. The model was used to make the design guidelines for the necessary size/geometry of the air cavity as a function of local wind speed, insulation thickness and length of the roof.

Demand Control Ventilation and indoor climate

Energy efficient ventilation and good indoor climate are important topics throughout the guidelines. Demand controlled ventilation has been a gamechanger, and research through several projects such as; reDuCeVentilation (2009-2013), ForKlima (2013-2016), Svalvent (2017-2021) and BestVent (2016-2020), has been a continuous source for guidance and improved practice in the building industry. Some relevant guides in BFS are mentioned here:

- Demand Control Ventilation, System solutions and regulation, guide 552.325 (2016). A systematic overview of types of demand control ventilation systems, as well as appropriate control systems. At that time, such overview was totally missing, and many time-consuming errors were reported in operation of systems.
- Demand Control Ventilation, Requirements upon purchase and control upon handover, guide 552.324 (2016). Practical research-based advice and control routines developed to prevent and reveal malfunctions.
- Ventilation in schools, guide 552.311 (2022). Requirements for indoor climate and suitable solutions for teaching rooms and living spaces in schools are described. These requirements ensure good operation and energy-economy based on criteria for suitable indoor climate.

Key researchers, positions they held at SINTEF Community at the time of the research, and their expertise are listed below. Abbreviations used; Research Scientist (R), Senior (S), Research Manager (RM)

Lars Gullbrekken, SR and RM (Building physics), 2010- present
Silje Asphaug, R (Building physics), 2012- present
Berit Time, Chief Technology Officer (Climate adaption), 1997- present
Igor Sartori, SR (energy, end-use flexibility), 2008- present
Kari Thunshelle, SRS (Ventilation and indoor climate), 2001- present
Sverre B. Holøs, SRS (Ventilation and indoor climate), 2006- present
Mads Mysen, Chief Scientist (Ventilation and indoor climate), 1997- 2018, Currently at GK
Sondre Aasbø, Advisor (Building and construction), 2018- present
Ida Lund Segtnan, Senior Advisor (Building and construction), 2014- present
Marianne Kjendseth Wiik, R (Life Cycle Assessment /Life Cycle Cost), 2014- present
Selamawit Mamo Fufa, SR (Life Cycle Assessment /Life Cycle Cost), 2013- present
Inger Andresen, SR (energy, emissions), 2013- 2018, Currently at NTNU

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Gullbrekken, Lars: Climate adaptation of pitched wooden roofs. Doctoral theses at NTNU, 2018:124, Norwegian University of Science and Technology, Faculty of Engineering, Department of Civil and Environmental Engineering. ISBN: 978-82-326-3038-7. 2014

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Holøs, S.B., A. Yang, K. Thunshelle og M. Mysen. Effect of ventilation on perceived air quality in 18 classrooms. IOP Conference Series: Materials Science and Engineering 2019: 609:042038- https://doi.org/10.1088/1757-899x/609/4/042038

4. Details of the impact

The process from research to impact

There is a close collaboration between SINTEF researchers and the scientific advisors and editors responsible for the SINTEF Building Research Design Guides (BFS), through internal projects, or as part of the dissemination in the research projects. Research results suitable to be disseminated by BFS will be selected, explained, quality assured and implemented in form of guides in BFS. In this process, we use a committee with members from all different parts of the construction industry in Norway. The Norwegian Building Authority and Standards Norway are among the members of the committee. The committee has an advisory function and contributes to develop BFS through technical discussions, identifying focus areas which are useful for the construction industry, interpretations of how regulatory requirements can be solved and other important aspects for the Norwegian construction industry. Our dialogue with the committee also provides useful feedback to our research work.

The main impacts of SINTEF Building Research Design Guides (BFS) can be categorised in two themes.

4.1 National Knowledge Tool providing High Quality in the Construction sector

The SINTEF Building Research Design Guides (BFS) adapts experience and results from research into a practical benefit to the construction industry. The main impact is to provide guidelines, solutions and recommendations that encourage high quality in the planning, design and construction of buildings. The concise guidance on the principles and practicalities of construction is in conformity with the regulations to the building act (TEK) and has become a standard of quality and the most authoritative and important tool to ensure high quality buildings in Norway.

The SINTEF Building Research Design Guides (BFS) consists of approximately 800 design guides. In 2022, the website logged 5,117,886 pageviews. BFS is offered through subscription and has

approximately 4000 customers and about 20,000 users. The design guides are used by architects, consultants, contractors, and builders in the construction industry, as well as students in high schools, colleges, and universities.

The Norwegian Building Authority (DIBK) recommends using The SINTEF Building Research Design Guides as documentation in construction projects, as basis for control plans and check lists, and for overall competence building. DIBK refers quite extensively to The SINTEF Building Research Design Guides in the "Regulations on technical requirements for construction works (TEK17)" and its guidance document, as a main reference (together with standards) for pre-accepted solutions.

Reviews for each guide may vary, depending on the relevance of the topic for different actors. Some themes can be relevant for many, and some can be relevant for a narrow range of users. Table below shows the number of page reviews for some of the named guides in 2022.

Design guide	Pageviews in 2022
525.207 Kompakte tak	36.047
473.020 Nullutslippsbygninger (ZEB). Retningslinjer og beregningsmetoder	1.164
473.003 Energieffektive bygninger. Begreper og definisjoner	1.094
525.101 Skrå, luftede tretak med isolerte takflater	21.889
552.324 Behovsstyrt ventilasjon (DCV). Krav ved innkjøp og kontroll ved overlevering	291
552.325 Behovsstyrt ventilasjon (DCV). Systemløsninger og regulering	358
552.311 Ventilasjon i skoler	1.719

4.2 Education

The training office for the carpentry trade (Opplæringskontoret for tømrerfaet) and Datapower have, in close cooperation with Byggmesterforbundet and SINTEF Community, developed an online training offer (course) for the carpentry profession. SINTEF Community has contributed with content from the Building Research Design Guides. The e-learning courses consist of videos, theory, descriptions, and various qualifying examinations.

SINTEF has developed training courses for the ventilation and building automation industry. A combination of lectures and lab training attracts service personnel, designers, installers and building owners at both basic and advanced levels. The courses are built on content from a long list of Building Research Design Guidelines and research projects. The content is also of importance for master students as well as the young ventilation technicians and their teachers.

4.3 Value Proposition

BFS has been used as a basis for design, work description, and documentations in building industries. The design guides describe principles and necessary performances that should be used as a basis for design. The instructions have examples of solutions that can be adapted to fit into each project. The design guides can also be used as a basis for drawings and descriptions, or at the construction site. Referring to solutions in the design guides can serve as documentation for design and execution in the construction project.

Harald Nikolaisen, CEO at Statsbygg, describes (in October 2018, for 60 years anniversary of BFS): "BFS provides help in a difficult working day. One of the greatest values that BFS offers for Statsbygg, is to have a reference (along with standards) to assess whether a design is acceptable."
Lise Rystad, Managing Director at NSW Aarchitecture, states during the same occasion: "Through solid instructions offered by BFS, we have the store of knowledge to create fine projects and good architecture."

Our recent customer survey indicates in average a "Very Satisfied Users" for the categories, design or choice of solutions, construction, documentation, and risk reduction.

5. Sources to corroborate the impact

A recent survey conducted in 2023 by Barcode Intelligence reveals that the SINTEF Building Research Design Guides are highly regarded by customers and users across various professions in Norway. According to Barcode, the results rank among the best in terms of customer satisfaction in the corporate market. Customers also give SINTEF a very high reputation score, emphasizing the significant trust and brand value associated with the organization.

In 2014 the SINTEF Building Research Design Guides was awarded the Nordic Moisture Safety Prize. The jury explains: “SINTEF Byggforsk (previous name of SINTEF Community) has together with the construction industry made knowledge available and applicable through the BFS for more than 50 years. The online quality standard is today a national knowledge tool for the entire construction industry. We find it very important that SINTEF Byggforsk conveys national and international research results and experiences to the construction industry in order to promote quality and prevent future building damage. It is our hope that this award will stimulate to continue the work for better building quality and prevention of moisture problems.”

SINTEF Community, Case 2

Institution: SINTEF AS
Administrative unit: SINTEF Community
Title of case study: Resource Management in Low- and Middle-Income Countries (LMIC)
Period when the underpinning research was undertaken: 1990- 2022
Period when staff involved in the underpinning research were employed by the submitting institution: 1988- present
Period when the impact occurred: 2012-2022

Summary of the impact
Resource Management as part of circular economy with a global sustainable focus is heart of this impact case. SINTEF Community has developed several research and development projects throughout three decades, in close collaboration with Low- and middle-income countries (LMIC), with the aim to contribute to a sustainable development in LMIC.

Marine plastic waste from five Asian countries has been used as a substitution to fossil fuel in industries such as cement manufacturing in the same countries, through demonstration plants. Combating marine plastic pollution, improving treatment of non-recyclable plastic waste, and positive impact on the environment (reduction of waste landfill, plastic pollution and spread of microplastic) and climate change (reduced CO2 emission) are the main impacts in the **OPTOCE** project.

The **Indo- Norwegian** project implemented international best practice and conducted pilot demonstrations in India by recycling Construction and Demolition (C&D) waste into recycled aggregates used for concrete production. Saving of virgin raw materials, reduced CO2 emission and health impacts due to preventing ground water pollution are the main impacts of this project.

2. Underpinning research

SINTEF Community has developed several projects in the last 30 years, with support from Norwegian authorities to contribute to the global sustainable development in LMIC. We will focus on two projects, one focusing on resource management and circular economy of ocean plastic in five Asian countries, and the other one on construction and demolition waste in India.

The project Ocean Plastic Turned into an Opportunity in Circular Economy (**OPTOCE**) has showcased how the cement industry can be involved and increase the treatment capacity for Non-Recyclable Plastic Wastes in China, India, Myanmar (limited activities), Thailand, and Vietnam and thereby contribute to reducing the release of plastics to the sea.
Countries targeted by OPTOCE currently have the highest plastic consumption in the world, producing an estimated 176 000 tonnes of plastic waste per day, or around 64 million tonnes annually, large quantities of which are dumped in landfills. The OPTOCE countries also produce around 75% of the world's cement, steel and electricity in tens of thousands of plants utilising vast amounts of coal, thus contributing over 30% of the world's CO2 emissions.

“Co-processing” is the terminology used when parts of coal inputs to these processes is replaced with non-recyclable waste, and this represents an approach which can save significant amounts of coal, reduce the release of plastics to the ocean and greenhouse gas emissions. Co-processing has been practiced in Norway for the last 30 years and has shown to be cost-effective, resource-efficient and environmentally sound compared to the alternative, incineration. This concept represents circular economy in practice and incorporates waste treatment with existing industrial

production, which is preferred to incineration (Recovery) and landfilling (Disposal) in the Waste Management Hierarchy.
Through OPTOCE, SINTEF runs pilot demonstrations replacing coal with non-recyclable plastic waste for co-processing in local plants in selected countries. Also, SINTEF has entered into cooperation agreements with relevant project partners in all selected countries. There are agreements with national and local authorities, leading waste management companies and the industry, universities, Non-Governmental Organizations, as well as international organisations such as UNIDO (United Nations Industrial Development), UNDP (UN Development Program) and UNEP (UN Environmental Programme). Prior to the OPTOCE project, SINTEF has demonstrated the utility value of co-processing hazardous waste in cement facilities, mainly in Norway and China.

Recycling of the waste from construction, re-modelling, repair, and demolition of any civil structure is a major component of circular economy world-wide. C&D waste are currently recovered at a low level in India. The **Indo-Norwegian** project has been initiated between Central Public Works Department (CPWD), Ministry of Housing and Urban Affairs, Govt. Of India and SINTEF where the aim is to increase the treatment and recycling capacity for construction and demolition wastes in India. The project implements international best practice, perform various capacity building activities and conduct pilot demonstrations. It has focused on the production of recycled aggregates from C&D waste with a documented stable quality applied in both bound and unbound user applications (e.g. concrete production and road construction).
Construction and Demolition waste (C&D waste) is one of the largest global solid waste streams. It is estimated that 150-750 million tons of C&D waste are generated every year in India. The recycling level is low and there is a huge potential for increased utilisation with significant positive impact on climate and environment.
C&D contains wood, plastic and paper rejects, ceramics, mortar, concrete etc. The heavy inorganic part (from concrete and masonry) could be processed and refined into recycled aggregates which can substitute natural aggregates in various amounts. Several successful demonstrations have been conducted in India, in order to verify the practical, technical and environmental applicability of recycled aggregates. SINTEF also launched the recycling potential of C&D in the RCN project 2009-2012

Key Researchers:
Kåre Helge Karstensen. Chief Scientist, Circular economy, cement production and waste treatment, 1988- present.
Christian John Engelsen. Chief Scientist, Circular economy, cement production and waste treatment 1998- present.
Anneli Paulsen. Research Manager and scientist, circular economy, 2019- present.
Line Døssland. Scientist, in-organic chemist and material expert, 2021- present.
Palash Saha. Senior advisor, Circular economy, cement production and waste treatment, 2014- present.
Harald Justnes. Chief Scientist, Material technology, cement and concrete. 1998- present.
Monica Strøm Nodland, Research Manager and scientist, Chemist and material technology, 2005- present

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Engelsen, C. J., Nath, K. P. and Kandasami, S. (2022). "Recycled concrete aggregates in new concrete – Full scale demonstration in Navi Mumbai", The Indian Concrete Journal, Vol. 96, No. 1, pp. 49-57.

Engelsen, C. J., Malhotra, S.K., Bhatiani, G., Nath, K. (2020). "Detailed assessment of the technical properties of recycled aggregates from mixed C&D waste" The Indian Concrete Journal, Vol. 94, No. 8, pp. 32-39.

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4. Details of the impact

Impact of R&D activities in collaboration with LMIC, appears through a long-term process, and is challenging to measure. Impact from research activities for LMIC is not only environmental and economical, but also involves the public, private and governmental awareness. We have experienced that sharing "lessons learned" in a regional multi-stakeholder forum will enable replication, creating a huge impact for LMIC.
We choose to divide the impact into two main categories:

<u>Environmental and Health impacts</u>

OPTOCE: Several types of large volume non-recyclable plastic waste have been tested in China, India, Thailand and Vietnam, demonstrating that co-processing in local cement kilns is technical feasible and environmentally acceptable. It is shown that emissions of all air pollutants, also dioxins, are unaffected by plastic-waste feeding. These cement plants will actively prevent a minimum of **100,000 tonnes of plastic waste** from reaching the sea, simultaneously resulting in a yearly **saving of at least 100,000 tonnes of coal.**

Indo-Nor: The CO2 reduction potential due to recycling of C&D waste in India is calculated by SINTEF to be 6.1-12.4 Mt of CO2 per year. Proper handling, storage and treatment of C&D waste will largely prevent mixing of C&D waste and MSW (Municipal solid waste), another large volume waste stream), which facilitates the recovery of both waste streams.
In urban areas where there is limited sanitary landfill capacity, the proper and secure handling is a challenge. The environmental and health impacts may be serious and lead to ground water pollution and diseases for humans. Improvement of the current waste management practice, i.e. less human contact with waste sites, will therefore benefit vulnerable groups in the society, in particular women and children.

<u>Public, private and governmental awareness impact</u>

OPTOCE inhabits an important niche in the overall development of work against marine plastic pollution. National waste management plans in the region take co-processing into account. In

India, the 2016 Waste Management Rules require industrial units within 100 km from waste-based refuse-derived fuel plants to replace at least 5 % of their fuel requirement with refuse-derived fuel. Moreover, co-processing is an important pillar in the Chinese waste management strategy and in circular economy, as well as an integrated part of the National 13th Five-year plan on Ecological and Environmental Protection.

In China, the pilot project has been presented at industry conferences, as well as to the local government and communities. The government is serious about tackling the issue of plastic pollution and recognises that the cement industry can offer a solution for disposal of non-recyclable plastic waste. There are also positive effects for the populations living around the Huaxin cement plants. The cement plant workers predominantly live in the rural communities surrounding the plant, which are not served by municipal waste collection. The workers have begun to bring their plastic waste to work to feed into co-processing, rather than dumping the waste in the river and surrounding landscape. The Huaxin cement plant offers to collect certain types of plastic waste from designated locations in the plant vicinity, deposited by local residents such as farmers. The residents do not receive financial incentives to engage in this behaviour, but rather do so out of a shared community desire to reduce environmental pollution.

In India, awareness raising consisted of educating stakeholders such as pollution control board representatives, municipal officers and industry stakeholders, expanding the support for co-processing. As impacts of this awareness raising, we can mention growing interest in management of dumpsites, local involvement of pollution control boards, and new discussions of potential investment in and growth of a market for pre-processing. The pilot in OPTOCE has helped building the business case for involved actors, by increasing the percentage of non-recyclable plastic waste in cement production.

Indo-Norwegian:
SINTEF has played an important role in the development of governmental regulations and requirements in India. The regulative framework for C&D waste management before 2016, was covered in the Municipal Solid Waste Handling Rules of 2000. In these rules, C&D waste was treated in general terms, without any criteria or defined stakeholder responsibilities. As part of the preparations for the India-Norway C&D waste Phase I initiative, there was close communication between Ministry of Housing and Urban Affairs (MoHUA), CPWD and SINTEF. One of the first milestones achieved was that MoHUA stated to create environmentally friendly recycling facilities for C&D in all cities with a population of over 100 000 (MoHUA, 2012). This was achieved as a direct result of the internal conference meeting with SINTEF and MoHUA 3rd of May 2012.

In 2016, SINTEF signed an MoU with CPWD (photo). At an initial stage of C&D waste management in India, SINTEF emphasised the importance of including the key elements Waste Management Plan and Certificate of Completion, which also became part of the C&D rules 2016 in India.
Goa Waste management Corporation (GWMC) entered a MoU with SINTEF in 2018 with an aim to increase the treatment and recycling capacity for C&D wastes.

SINTEF has provided a numerous of keynote speeches in conferences and organised workshops with the relevant stakeholders in Delhi, Mumbai, Goa, Nagpur, Cochin, Kolkata, Chennai etc. Close

interactions with government stakeholders have been conducted, including CPWD, MoHUA, Municipalities mentioned above. SINTEF has collaborated closely with the very large construction companies Godrej & Boyce Mfg. Co. Ltd. and Larsen & Toubro Ltd. (L&T). SINTEF has interacted with many of the C&D recycling operators in India (e.g. EverEnviro Resource Management Pvt. Ltd., Indias largest C&D recycling unit) as well as the world leading technology equipment provider CDE Asia belonging to CDE Group. SINTEF has also provided input on a regular basis to the Bureau of Indian Standards (BIS) committee (CED 2:2/P8, BIS) responsible for IS 386 and the rules for using recycled C&D waste as aggregates in new concrete.

Importants stakeholder like CPWD, industry, Goa Waste Mangement Corporation etc. have visited Norway for training seminars and site visits, including Sørumsand High School, which was completed in 2003, as the first of its kind. Half of the concrete in the building was manufactured with recycled concrete aggregates from construction waste.

5. Sources to corroborate the impact (indicative maximum of ten references)

Norad – the Norwegian agency for development cooperation – is a professional body under the Ministry of Foreign Affairs (MFA). In their Ocean Report, 2021, Norway's support for a sustainable ocean acknowledges SINTEF's contribution;
"Environmentally sound management of non-recyclable plastic waste is technically complicated and costly, and there is a lack of capacity and resources to manage the increasing amounts of this waste. In China, India, Thailand and Vietnam, SINTEF has continued its work to investigate how energy-intensive industries such as cement manufacturing can benefit from utilising the high-energy content of non-recyclable plastic waste. In 2021, together with partners in the private sector and government institutions, SINTEF has investigated the feasibility of using non-recyclable plastic waste from Vietnam's largest paper recycling plant and the feasibility of using waste from shoe/footwear manufacturing as co-fuel at the INSEE Hon Chong cement plant in Kiến Giang province."

The Royal Norwegian embassy in New Dehli has published about SINTEF's work in India (2012) in a news article. The achievements of Kåre Helge Karstensen and Christian Engelsen were acknowledged.

Kåre Helge Karstensen received the Lifetime Achievement Award for his dedicated work in documenting Co-processing as a sustainable waste management option, at the 13th International Conference on Sustainable Waste Management and Circular Economy & IPLA Global Forum 2023 in Mumbai (photo).

SINTEF Community, Case 3

Institution: SINTEF AS
Administrative unit: SINTEF Community
Title of case study: Zero emission and energy efficient buildings
Period when the underpinning research was undertaken: 2000-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 1997- present
Period when the impact occurred: 2012-2022

1. Summary of the impact

This impact case describes the impacts from our research projects within zero emission and energy efficient buildings. Together with partners, SINTEF Community has strongly contributed to developing new solutions for the energy- and building sectors including design guidelines, regulations, education, and increased knowledge. The projects have contributed to impacts related to efficient use of energy, renewable energy generation, energy flexibility, improved indoor environment, and reduced climate emissions.

2. Underpinning research

The main focus of this impact case is generated from the Research Centre on Zero Emission Buildings (FME ZEB, 2009-2017) and the Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN, 2017-2024). Both FME ZEB and FME ZEN were hosted by NTNU and implemented and lead together with SINTEF.

FME ZEB was finalised in 2017, with the main objective to develop competitive products and solutions for existing and new buildings that will lead to market penetration of buildings that have zero emissions of greenhouse gases related to their production, operation and demolition. ZEB results have been published in close to 1000 scientific articles, popular science articles and presentations.

In 2017, FME ZEN started, with the aim to create solutions for the zero emission buildings and neighbourhoods of the future. The FME ZEN research is carried out at different levels from more engineering orientated questions of building design and modelling to questions of integration into the wider energy system; questions of low-carbon transport; and social science issues of stakeholder participation; citizen engagement; and business model development. The Mid-term evaluation of the centre organised by the Research Council of Norway (RCN) indicates that the Centre contributes to the forefront of international research on the transition towards low-carbon settlements and societies.

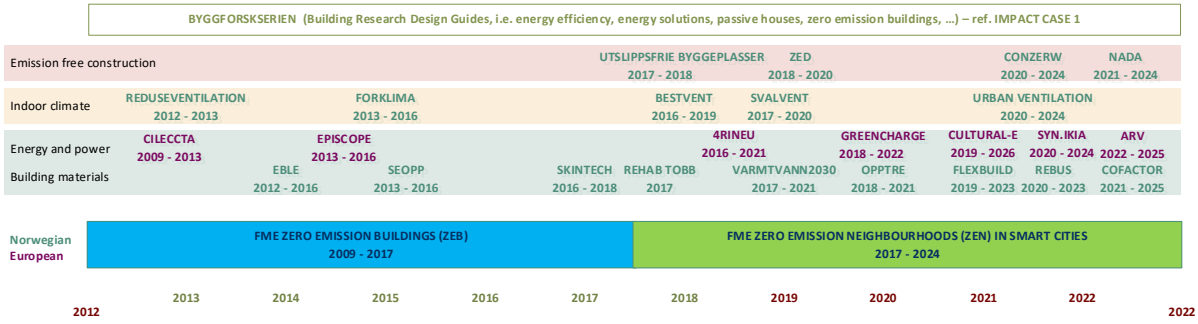

Fig. 1. Research projects within zero emission and energy efficient buildings implemented from 2012 to 2022.

A number of spin-off or related research projects were undertaken during the period of ZEB and ZEN, as outlined in Fig. 1. The national (green text in the figure) and international (purple text in the figure) research projects implemented in the period, have targeted specific areas within zero

emission and energy efficient buildings, such as energy use and energy efficiency, ventilation and indoor climate, end-use flexibility, emission free construction, and circular economy. They are to a large degree based on the research work of the centres, illustrating their potential and relevance for further development. The description of the impact case will also include examples from these projects.

Key researchers and positions they held at SINTEF Community at the time of the research
Abbreviations used: Research Scientist (R), Senior Research Scientist (SR), Research Manager (RM).

Maria Justo Alonso, SR (energy, ventilation), 2009- present
Inger Andresen, SR (energy, emissions), 2013- 2018, Currently at NTNU
John Clauss, R (energy, end-use flexibility), 2018- present
Tor Helge Dokka, Chief scientist (energy, passive houses), 2001- 2013, Currently at Skanska
Kristin Fjellheim, SM and RM (LCA/LCC), 2020- present
Øystein Fjellheim, RM (energy), 2017- 2023, Currently at Caverion
Selamawit Mamo Fufa, SR (LCA/LCC), 2013- present
Steinar Grynning, S Business Developer (building materials), 2008- present
Lars Gullbrekken, SR and RM (building physics), 2010- present
Matthias Haase, SR (energy), 2007- 2020, Currently at Zurich University of Applied Sciences
Åshild Lappegard Hauge, SR (environmental psychology), 2009- 2019, Currently at Univ. of Oslo
Terje Jacobsen, Vice President, Research (energy, emissions), 1981- 2023 (currently partly retired)
Ann Kristin Kvellheim, SR (energy, emissions), 2017- present
Carine Lausselet, SR and RM (building materials), 2021- present
Anne Gunnarshaug Lien, SR (energy, architecture), 2010- present
Synne Krekling Lien, R (energy, end-use flexibility), 2018- present
Karen Byskov Lindberg, SR (energy, end-use flexibility), 2018- 2022, Currently at Aneo
Nicola Lolli, SR (energy, life cycle assessments), 2013- present
Mads Mysen, Chief Scientist (energy and ventilation), 1997- 2018, Currently at GK
Nina Holck Sandberg, SR (energy), 2019- present
Igor Sartori, SR (energy, end-use flexibility), 2008- present
Christofer Skaar, SR (LCA), 2016- 2023, Currently at Asplan Viak
Kristian Stenerud Skeie, R (energy), 2013- present
Åse Lekang Sørensen, SR (energy, end-use flexibility, 2016- present
Judith Thomsen, SR (housing research, end user perspective, architecture), 2009- present
Kari Thunshelle, SR (energy and ventilation), 2001- present
Berit Time, Chief Scientist (climate adaption), 1997- present
Harald Taxt Walnum, R (energy, end-use flexibility), 2017- present
Marianne Kjendseth Wiik, R (LCA/LCC), 2014- present

3. References to the research

Low-energy buildings (receiving best review paper 1998-2007 in Energy and Buildings):

Sartori, I, Hestnes, A.G. (2007) Energy use in the life cycle of conventional and low-energy buildings: A review article, *Energy and Buildings*, Vol. 39, https://doi.org/10.1016/j.enbuild.2006.07.001.

Lessons learnt from FME ZEB:

Wiik M.K., Fufa S.M., Kristjansdottir T., Andresen I. (2018), Lessons learnt from embodied GHG emission calculations in zero emission buildings (ZEBs) from the Norwegian ZEB research centre, *Energy and Buildings*, Vol. 165, https://doi.org/10.1016/j.enbuild.2018.01.025.

Building energy renovation:

Moschetti R., Brattebø H., Skeie K.S., Lien A.G. (2018), Performing quantitative analyses towards sustainable business models in building energy renovation projects: Analytic process and case study, *Journal of Cleaner Production*, Vol. 199, https://doi.org/10.1016/j.jclepro.2018.06.091.

Examples from FME ZEN:

Sandberg N.H., Næss J.S., Brattebø H., Andresen I., Gustavsen A. (2021), Large potentials for energy saving and greenhouse gas emission reductions from large-scale deployment of zero emission building technologies in a national building stock, *Energy Policy*, Vol. 152, https://doi.org/10.1016/j.enpol.2020.112114.

Lindberg K.B., Bakker S.J., Sartori I. (2019), Modelling electric and heat load profiles of non-residential buildings for use in long-term aggregate load forecasts, *Utilities Policy*, Vol. 58, https://doi.org/10.1016/j.jup.2019.03.004.

Taveres-Cachat E., Grynning S., Thomsen J., Selkowitz S. (2019), Responsive building envelope concepts in zero emission neighbourhoods and smart cities - A roadmap to implementation, *Building and Environment*, Vol. 149, https://doi.org/10.1016/j.buildenv.2018.12.045.

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Nocente A., Time B., Mathisen H.M., Kvande T., Gustavsen A. (2021). The ZEB Laboratory: the development of a research tool for future climate adapted zero emission buildings. *J. Phys.: Conf. Ser.* https://iopscience.iop.org/article/10.1088/1742-6596/2069/1/012109.

Emission-free building and construction sites:

Fufa, S. M., Wiik, M. R. K., Mellegård, S. (2019). Lessons learnt from the design and construction strategies of two Norwegian low emission construction sites. *IOP Conf. Ser.: Earth Environ. Sci.* 352 011002. https://doi.org/10.1088/1755-1315/352/1/012021.

4. Details of the impact

4.1 Defining and implementing ZEB and ZEN concepts, Knowledge transfer

SINTEF has played a pioneering role in advancing ZEB and ZEN concepts, contributing to a range of activities – from developing definitions and tools, to showcasing proof-of-concepts in full-scale pilot buildings. This is done in close cooperation with NTNU and other partners, engaging stakeholders from diverse sectors such as the building and energy sector, manufacturers, organisations, and government entities.

When **the ZEB Centre** started in 2009, it was among the first initiatives to look at greenhouse gas (GHG) emissions from buildings in a life cycle perspective. This focus has *promoted energy efficiency* in the use phase, investment in new local renewable energy technologies, and *reduction of GHG emissions* from materials used, the construction process and end-of-life stage of buildings. Zero Emission Buildings, a technical book published in 2017, disseminates the findings.

The ZEB Centre has produced a wide range of results and innovations. SINTEF researchers have been central in the activities, in close and ambitious cross-disciplinary collaboration with the partners, who now are including zero emission buildings in their business strategies. Nine actual building projects, including residential, commercial and public buildings, act as proof of the viability of the ZEB concept. These buildings have enabled the testing and demonstration of the ZEB definition, evaluation of tools, products and systems, and calculation rules for documenting ZEBs, all developed in the centre. Key results are presented in the ZEB Final report.

Norwegian society has become increasingly aware of the need to increase energy efficiency and reduce CO_2 emissions, during and after the lifetime of ZEB, due to dissemination of the results in both scientifical and public arenas. Large and small municipalities, companies and international actors have observed the activities taking place within the research centre and contacted SINTEF Community asking for advice and support in their work towards developing and building zero emission buildings and communities.

In **FME ZEN** the efforts are continued, now focussing on the neighbourhood level. The ZEN Centre has 9 pilot projects spread across Norway, as well as ZEN cases and living labs, all essential for learning and gaining in-depth knowledge. Here researchers and partners meet, and innovations are

tested and demonstrated. A dedicated homepage is developed by Statsbygg and SINTEF/ZEN for one of the pilots, ZEN pilot Evenstad, sharing lessons learned from the innovative energy solutions at the university campus. SINTEF Community is central in the ZEN research, development and innovation activities, in close collaboration with the partners. The ZEN Innovation report provides an overview of research innovations per 2020.

4.2 Design guidelines, standardisation, regulations, and policy development

To provide research-based input to design guidelines, standardisation, regulations, and policy developments is central in a number of SINTEF Community's projects. This section includes some examples.

Guidelines: Research projects develop practical recommendations for planning and improving energy systems. An example is VarmtVann2030, with guidelines for domestic hot water systems in SINTEF Fag 80 and SINTEF Fag 81. Within ventilation, the project reDuCeVentilation provided "requirements and commissioning" in 2014, to help building owners to acquire well-functioning demand-controlled ventilation. Within emission-free construction, SINTEF's research guided Oslo municipality in establishing minimum requirements for fossil-free and emission-free construction projects, resulting in a tangible reduction in emissions and influencing society, public policy, and the environment. SINTEF Community actively addresses knowledge-sharing challenges in emission-free construction by disseminating insights and lessons learned from leading municipalities, fostering collaboration and industry-wide progress (SINTEF Fag 89, Utslippsfri byggeprosess i Oslo). Within energy planning, SINTEF's energy and power calculation tools (PI-SEC Scenario Calculator) aids stakeholders in estimating and planning energy demands for buildings and neighbourhoods. A "Flexibility Suite API" is available for partners, providing energy demand load profiles (PROFet) and end-user flexibility potential (FLEXor). Finally, the SINTEF Building Research Design Guides is an outstanding and extensively used research dissemination tool, as detailed in Impact case 1.

Standardisation and regulations: Research results provide a basis for improved standardization and building regulations. Results from the ZEB Centre were important input for a national standard on the calculation of greenhouse gas emissions in buildings (NS3720:2018). Another example is the energy profiles in Standard Norge SN-NSPEK 3031:2020 «Energy performance of buildings », where energy data from VarmtVann2030 was used as a direct input for revised standard-specifications for domestic hot water. On a European level, ZEB and ZEN research is central in the JRC technical report "Defining Zero-Emission Buildings", which is written by the European Commission's science and knowledge service to support the revision of the Energy Performance of Buildings Directive (EPBD). EPBD is essential to set out how the EU can decarbonise the building stock by 2050.

Policy development: Research results also provide basis for input to political processes. A recent example is Arendalsuka 2023, where FME ZEN invited to debates within energy efficiency in buildings. In the political report "More of everything — faster" (NOU 2023:3) from the Energy Commission, research from SINTEF Community / ZEN is described as background information ("Mål om 10 TWh energisparing i bygningsmassen" (Sandberg 2022), "Potensial- og barrierestudie, Energitjenester i næringsbygg" (SINTEF 2020). In the ZEN study "Energy saving potential in buildings towards 2030 and 2050", researchers from SINTEF and Skanska examined the most effective ways to achieve national energy goal.

4.3 Enabling technologies for zero emission and energy efficient buildings

Innovative technologies and building solutions are demonstrated in several research projects. The following examples illustrate SINTEF's role and the outcomes of some of these initiatives.

The Norwegian Zero Emission Building Laboratory (ZEB Laboratory) was constructed in Trondheim during the ZEN project period. ZEB Laboratory is a complete demonstration of a Zero Emission Building, which has been in operation since 2021. It is a full-scale office building (4 stories high and 2000 m²) where building façades, components and technical systems can be modified and

replaced. NTNU and SINTEF Community were in charge of the construction and are also responsible for the operation of the building. ZEB Laboratory aims to be an arena where new and innovative components and solutions are developed, investigated, tested, and demonstrated. Some examples already tested are: 1) Heat storage unit (PMC) that utilises the phase change material biowax. 2) Surplus power from solar panels (BIPV) is delivered to NTNU's own power grid. 3) New ventilation principles, including natural, mechanical and hybrid ventilation. 4) Stormwater system combining permeable pavements, rain gardens and detention basin (developed in SFI-Klima 2050).

SINTEF has been instrumental in advancing emission-free construction projects through various innovation initiatives. SINTEF played a crucial role in realizing the first large electric excavators, tested on groundbreaking and world-first emission-free construction sites in 2019.

Wooden single-family dwellings, which are a common Norwegian building typology, were renovated to nearly zero energy level. Small wooden dwellings are responsible for more than half of the total energy use in the Norwegian building stock. SINTEF Community led SEOPP and OPPTRE projects, cooperating with both industrial partners and authorities.

In 4RinEU, a residential building was renovated with prefabricated façade elements. SINTEF worked closely with Boligbygg and Lindal to realise the façade elements, with improved levels of insulation, PVs and balanced ventilation. This is a completely new technology and market in Norway.

In GreenCharge, SINTEF Community coordinated and supported the Oslo pilot, providing cost efficient home charging facilities for inhabitants in building blocks with 246 apartments. The charging facilities were combined with PV generation.

In Cultural E, SINTEF is advisor for the Norwegian pilot in Bærum, which is an apartment building (BREEAM Excellent) in wood, with geothermal heat-pump, balanced mechanical ventilation with heat recovery, an advanced building management system, solar cells, battery, load balanced charge points for Evs, and optimization strategies and building flexibility.

5. Sources to corroborate the impact

Bygg21s Betonghammeren 2022 was awarded to ZEB-Laboratory as an example of best practice in the construction sector. ZEB Laboratory was also the winner of the Government's award for Building quality in 2022.

FME ZEN was evaluated by the Research Council in 2021, with a very positive outcome: "The quality and outcome of the research carried out in the Centre is impressive at different levels …. This broad range of issues could pose a formidable challenge to the organisation and management of research in such a Centre, but at the same time the critical mass achieved in such a research Centre also provides a unique opportunity to deal with such questions in their connectedness and interrelatedness. The Centre does so in an excellent manner … Moreover, there is a good mix of industry focused and research-based projects, supported by the ZEN Labs and Pilots."

The book Zero Emission Buildings (2017) is used by students of architecture and engineering as well as practitioners looking for ways to contribute to a sustainable future. For example, it has been an integral part of the curriculum for the MSc in Sustainable Architecture at NTNU since its publication, with an annual uptake of approximately 30 students per cohort.

The ZEB pilot "Plus House Larvik" won the World Architecture News (WAN) Sustainable Buildings 2015 award. Plus House Larvik was created by Snøhetta architectural studio in partnership with SINTEF Community, ZEB partner Brødrene Dahl and Optimera.

Since 2010, more than 1350 professionals have participated at regular bi-annual courses in ventilation. SINTEF Community has provided research-based training within this field since 1976, focusing on healthy indoor environment, noise prevention and energy-efficient systems.

SINTEF Community, case 4

Institution: SINTEF AS
Administrative unit: SINTEF Community
Title of case study: Traffic safety and security
Period when the underpinning research was undertaken: 1999-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 1983- present
Period when the impact occurred: 2012-2022

1. Summary of the impact

Traffic accidents pose a major transport safety challenge. The Vision Zero initiative aims for zero fatalities and serious injuries in roads, including road tunnels as challenging road segments for traffic safety. Another challenge is related to the human factor in accidents, e.g. the expertise of young drivers and the behaviour of children in traffic. SINTEF has contributed to road safety and security, tunnel traffic safety, emergency exit systems and traffic safety for young road users. SINTEF's research has had a significant impact on road tunnel safety design, and human aspects with great emphasis on accident analysis, safety campaigns, driver education and understanding the brain of young road users.

2. Underpinning research

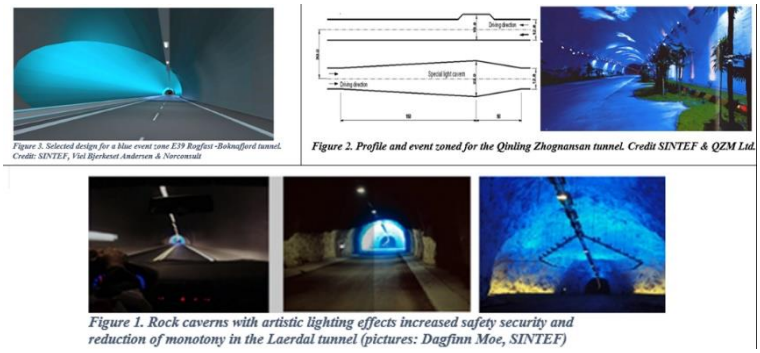


Figure 3. Selected design for a blue event zone E39 Rogfast-Boknafjord tunnel. Credit: SINTEF, Viel Bjerkeset Andersen & Norconsult

Figure 2. Profile and event zoned for the Qinling Zhognansan tunnel. Credit SINTEF & QZM Ltd.

Figure 1. Rock caverns with artistic lighting effects increased safety security and reduction of monotony in the Laerdal tunnel (pictures: Dagfinn Moe, SINTEF)

Tunnel safety and Security

Unlike open roads, driving in monotonous tunnels poses a safety risk due to reduced brain stimulation. SINTEF's 2018-2020 studies showed that varying tunnel width and lighting breaks spatial monotony and enhances driver alertness. This approach was first used in Norway's 24.5 km Laerdal tunnel in 1999 and later in China's 18.2 km Qinling Zhognansan tunnel (2008). SINTEF contributed by performing surveys, 3D model development, and driving simulator verification. The full-scale implementation has been applied in the ongoing E39 Rogfast-Boknafjord tunnel project, the world's longest and deepest subsea tunnel.

Key studies

A) Tunnel design for safety and security projects

- Norway (2011-2015) - Safety and design for Ryfast, 14 km subsea tunnel. Norwegian Public roads administration (NPRA) and Norconsult. SINTEF contributed with tunnel safety and security expertise.
- Norway (2017-2020) - E39 Rogfast 26 km subsea tunnel design modelling and simulation test of monotony reducing measures. Cooperation with NPRA, Viel Bjerkeseth Andersen, and Norconsult. SINTEF contributed creating a simulated tunnel to be visualised using VR, experimental design and execution, and data collection and analysis.

B) Fire safety Emergency Exit Systems and Self Rescue

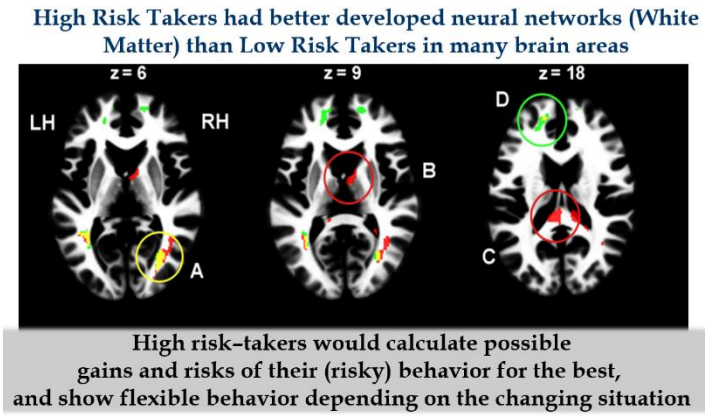
- USA (2012-2015) - Emergency exit signs and systems. National Highway Department and Texas Transportation. This work was sponsored by the American Association of State Highway and Transportation Officials (AASHTO), in cooperation with the Federal Highway Administration, and was conducted in the National Cooperative Highway Research Program (NCHRP), which is administered by the Transportation Research Board (TRB) of the National

Academies of Sciences, Engineering, and Medicine. SINTEF contributed with tunnel safety and security expertise.

- Norway(2018-2020) - Virtual Reality study of emergency exit systems to aid self rescue during road tunnel fires. Effect of visual and accoustic measures. E.g. continous LED lit handrail and accoustic beacons above emrgency exits. Work sponsored by the NPRA. SINTEF contributed with the study design, experimental work, data collection, and data analysis.

Young road users and traffic safety

In addition to the road infrastructure, the human factors play a major role in traffic safety. SINTEF has explored risk-taking behaviour among young drivers and the relation to brain activation. This is particularly relevant for understanding how different brain areas function in mediating risk-taking and social aspects of risky driving behaviour. The research took place in the Center for Cognitive Neuroscience in Turku (CNN Finland), as research partner to SINTEF, and was financed by the NPRA and CNN at the University in Turku.



Key studies

- Evaluation of the brain structures of young drivers according to the participants' actual risk-taking behaviour in a simulated driving task. The results suggested that increased risky behaviour during adolescence is not necessarily attributed to the immature brain, as conventional wisdom says. SINTEF has been the project manager and contributed with road user behaviour expertise, including study design, experimental work, and data analysis.
- Study using functional magnetic resonance imaging (fMRI) to investigate brain function and its correlation to risk-taking behaviour. The fMRI data were analysed for decision-making (whether to take a risk at intersections) and outcome (pass or crash) phases. Personality test-based groups showed no difference in the amount of risk-taking (similarly increased during peer competition) and brain activation. SINTEF's contribution is the same as the above point.
- Children, attention and cycling. Children aged 8-10 ride a lot in traffic. We know that the ability to orient oneself and use attention correctly is not yet fully developed in such young children. There is always an interaction between neurobiology and the environment one lives in. SINTEF evaluated how the child's brain is constantly changing, with the gradual development of many functions such as attention control. The study was financed by Trygg Trafikk.

Key researchers.

Abbreviation used: Senior Research Scientist (SR), Research Scientist (R):

- Gunnar Deinboll Jenssen, SR, Ph.D, traffic safety and psychology, 1988- present
- Claudia Moscoso, R, Ph.D., experimental research and VR studies, 2019- present
- Jo Skjermo, Senior Advisor, Ph.D, VR programming and research, 2013- present
- Dagfinn Moe, SR, neuroscience related to traffic safety, 1983- present
- Åsa S. Hoem, R, Ph.D, transport and mobility, 2014- 2022
- Isabelle Roche-Cerasi, R, Ph.D., traffic safety and user acceptance, 2007 - present

3. References to the research (in bold people employed by SINTEF)

1. **Jenssen, G.D., Skjermo, J., Hoem, Å.S., Arnesen, P., Södersten, C., Moscoso, C.** (2020). E39 Rogfast – Boknafjordstunnelen, simulatorstudie – effekt av monotonidempende tiltak. SINTEF Report 2020:00184 (ISBN 978-82-14-06405-6).

2. **Moscoso, C., Skjermo, J., Karlsson, H., Arnesen, P., Södersten, C., Hoem, Å.S., Jenssen, G. D.** (2023). Analysis of design and spatial factors for users' acceptance of rescue rooms in Norwegian road tunnels: An experimental study using VR. 10th international symposium on tunnel safety and security (ISTSS).
3. **Skjermo, J., Moscoso, C.,** Nilsson, H., Frantzich, H., **Hoem, Å.S., Arnesen, P., Jenssen, G.D.** (2023). Analysis of visual and acoustic measures for evacuations in road tunnels using virtual reality. 10th international symposium on tunnel safety and security (ISTSS).
4. Higgins, L., Carlson, P., Miles, J., Rozyckie, S., Averso, M., Graham, D., Seip, B., **Jenssen, G.D.** (2015). Emergency exit signs and Marking systems for highway tunnels. NCHRP report 216. Project 20-59(47). National Cooperative Highway Research Program, Transportation Research Board.
5. **Skjermo, J., Moe, D., Roche-Cerasi, I.,** Opland, R. (2022). Evaluation of Road Safety Education Program With Virtual Reality Eye Tracking. SN Computer Science journal, 3 (2), p. 1-11.DOI: https://doi.org/10.1007/s42979-022-01036-w
6. **Moe, D., Roche-Cerasi, I., Skjermo, J.,** Wigum, J.P. (2021). Barn, oppmerksomhet og sykling. Evaluering av ny opplæringsmodell basert på det vitenskapelige konseptet Mind, Brain and Education (MBE). SINTEF Report 2021: 01452 (ISBN 978-82-14-07707-0)
7. Kwon, M.S., Vorobyev, V., **Moe, D.,** Parkkola, R., Hämäläinen, H. (2014). Brain structural correlates of risk-taking behavior and effects of peer influence in adolescents. PLOS One, 9 (11). DOI: https://doi.org/10.1371/journal.pone.0112780

4. Details of the impact

SINTEF Community's research regarding evacuation from tunnels has contributed to design recommendations in several tunnels in Norway and abroad. The research results have been implemented through workshops, in which the results have been presented and discussed together with the responsible parties in different countries.

National Impact:

Norwegian Tunnel regulations and guidelines. An example can be found at

- N500 5.3.3 Evacuation lighting: Road tunnels must have continuous evacuation lighting. (2022). Evacuation lights are placed at least along one of the walls. In tunnels with emergency exits, the evacuation lights must be placed on the same side as the emergency exits.
- N500 5.3.3 Emergency stations. (2022). Emergency stations must be installed in road tunnels every 125 m.
- SINTEF Community in collaboration with NPRA and Stavanger University (UiS) has contributed to increased tunnel safety awareness through audiovisual campaigns on TV and social media. (2021).
- Evacsound, an acoustic emergency exit product, delivered by Trafsys, uses language neutral and intuitive Sound beacons for safer tunnel evacuation, which is implemented in two Norwegian tunnels (2021). This concept was developed and tested by SINTEF, in cooperation with NPRA and Trafsys.

International Impact:

- US guidelines for fire safety in road tunnels. NFPA 502 chapter 7 Road tunnels, A.7.16.1.3 Self-rescue and emergency exit recommendations have been included in US Tunnel regulations and guidelines, indicating that the studies "*have led to great improvement in helping direct people out of tunnels during an emergency*". Specifically, the US has applied the use of green photoluminescent running man and exit signs in Pennsylvania, Colorado and Virginia, and it is expected that more US agencies will adopt this technology in the future.
- China and Singapore; SINTEF Design and safety recommendations have been implemented in the world's longest motorway tunnel Qingling Zhognasan, in China in 2008. The same principles are applied in the underground science city project, in cooperation with Jurong

Town Corporation and Nanyang Technological University in Singapore (2014-2019). A BBC news article "Will we ever… live in underground homes?" highlights SINTEF research regarding underground psychology.

Young road users and traffic safety

SINTEF's research has evaluated several models of adolescence maturation and behaviour as a means to explain the neurobiology behind fluctuating emotions, impulsive risk-taking behaviour and diminished cognitive and emotional control. The research about adolescent brain systems and behaviours have suggested a need for rethinking specific ways in which we meet the needs of young people as they transition across these development stages and into adult life. The research findings have had important implications for legal and social policies relevant to both the protection and treatment of youth. The Huffington Post article "Are you a risk taker? You may be more intelligent" highlights SINTEF's research regarding to neuroscience risk-taking behaviour.

The Norwegian Public Roads Administration particularly, has used knowledge from this research in a traffic safety campaign from 2014-2017.

Traffic psychology has also been included as a permanent part of the curriculum at Nord University, Oslo Metropolitan University, Norwegian University of Science and Technology and The Norwegian Police University College.

Based on SINTEF's findings (in cooperation with Nord University) showing that children who participated in the new education program orientated themselves and used their attention better than their counterparts who followed the traditional program. These results developed a new road safety education program based on the last findings in Neuro-Education.

5. Sources to corroborate the impact (indicative maximum of ten references)

Traffic safety prize (2020-2021) to Senior Research Scientist Dagfinn Moe whom via his research, contributed to reduce traffic accident statistics (photo).

Norwegian and international guidelines about road tunnels

- Elaborated in section 4.

News and articles about evacuation from tunnels

- Rescue rooms in road Tunnels Acknowledgement of SINTEF's contribution by Arild P. Sovik, CEO, editor, senior advisor and tunnel expert.
- Basic safety measures saves lives in tunnels. SINTEF was responsible for the experimental studies and analysis of results. Reference to how the NPRA will also use the results to prepare a general information campaign designed to generate greater awareness about this topic.

Consulting and counselling to Norwegian and international authorities

- 2013: Invitation to assist Norwegian Safety Investigation Authority. Report on fire in a heavy goods vehicle in the Gudvanga tunnel (2015).
- 2014: Invitation to participate as tunnel experts in development of the underground city in Singapore
- 2019: Invitation to assist Norwegian Road Supervisory Authority (Vegtilsynet) in the implementation of measures, including regulation, which may strengthen preconditions for self-rescue in single bore road tunnels.

Recognition of excellence letter from Trygg Trafikk.

TRYGG TRAFIKK

SINTEF Community
Claudia Trinidad Moscoso Paredes

Ref.: BMJ 18.01.2024

Recignition of Excellence

SINTEF Community has for decades, through their excellent research, delivered important contributions to the work on road safety in Norway. The Norwegian road safety effort is regarded world leading among other things because of its application of research-based knowledge. The Norwegian Council for Road Safety, Trygg Trafikk, have among other stakeholders benefited greatly from the good cooperation with SINTEF Community.

SINTEF competence span several areas also applicable to road safety such as road infrastructure, transport planning, mobility, vehicle technology, automated driving, traffic psychology and neuroscience. A big part of this research has been used for direct application in the effort to find effective measures in the road safety area.

Yours faithfully,

Tanja Loftsgarden

Head of Department Research and Knowledge
The Norwegian Council for Road Safety

SINTEF Community- Case 5

Institution: SINTEF AS
Administrative unit: SINTEF Community
Title of case study: Climate adaptation and nature-based solutions
Period when the underpinning research was undertaken: 2015-2023
Period when staff involved in the underpinning research were employed by the submitting institution: 1997- present
Period when the impact occurred: 2019 - 2022

1. Summary of the impact

The concept of nature-based solutions (NBS) for climate change adaption has since 2015 emerged as a key tool for solving various environmental and societal challenges. NBS use the features and processes of a natural system, capabilities such as storing carbon and regulating water flow to achieve desired outcomes such as reduced disaster risk, increased aesthetic value, positive health effects and socially inclusive green transition. Impact of the research conducted by SINTEF Community and partners has paved the way for a wider uptake of NBS as a climate change adaptation measure to manage stormwater in Norwegian cities and surroundings. The impact has been in several dimensions, i.e. i) knowledge transfer, ii) new guidelines, and iii) new NBS products and concepts.

2. Underpinning research

The research was conducted by SINTEF Community in collaboration with partners through two research projects, namely the centre for research-based innovation "Risk reduction through climate adaptation of buildings and infrastructure", SFI-Klima 2050 (2015-2023), and the closely linked innovation project "Permeable interlocking concrete pavement for stormwater management" (Drensstein), 2017-2021. SINTEF Community was hosting and coordinated SFI-Klima 2050, and had the work package leadership on stormwater management in SFI-Klima 2050. SINTEF Community was also responsible for the research activities in the Drensstein-project, such as planning the test field, guiding the construction, follow-up the measurement, analyse and publish the results.

SFI-Klima 2050

The research methodology in Klima 2050 used two key factors, co-creation and pilot projects. The co-creation processes used teamwork and thematic meetings bringing together participants from research, public and private sectors. The pilot projects enabled that new nature-based solutions were tested in full-scale in-situ. At the same time the performance of NBS was demonstrated and documented, since we were able to fully instrument the sites to monitor the inflow and outflow of water. The following nature-based solutions were tested:

- A new system for infiltration and detention in series at Trondheim Town Square
- Several solutions for detention-based roofs at Høvringen. In total 6 different solutions were tested and documented through the lifetime of Klima 2050
- A green swale at Rv3 close to Elverum for managing road runoffs. The swale function at all three steps in the three-step approach for stormwater management has been documented.
- A novel stormwater management system comprising a series of solutions including permeable pavements, rain gardens and detention chamber was installed at the ZEB Laboratory

The full-scale in-situ sites have generated documentation of the performance of the different nature-bases solutions tested, as well as the deeper understanding of the water transport mechanism in these solutions.

In addition, in the process of establishing the pilot project, other challenges related to implementation of nature-based solutions have become clear. Here, we would like to emphasize the challenge of how such solutions should be documented. In collaboration with solution providers in Klima 2050, we have developed a framework to document nature-based solutions (Raspati et al. 2023). The framework provides a systematic documentation of the applied nature-based solutions in accordance with the principles of infrastructure asset management and in combination with a set of requirements in the newly adopted National Standard NS3456:2022 in Norway.

Finally, we would like to point to research results that use a nature-based strategy to actively reduce the flood potential in urban rivers. Using nature-based strategies for regulation of urban rivers has decreased the risk for flooding in downstream urban areas.

Drensstein

The Drensstein-project established a test field for permeable pavement, which is defined as a nature-based solution. The project partners Vikaune Fabrikker AS (project owner), Nordland Betong AS and ASAK AS (Fetsund, Hønefoss and Kristiansand) all produce concrete paving stones and market their products together through ASAK Miljøstein AS, which is a joint sales organization wholly owned by the factories. The test field enabled monitoring of the performance of different alternatives in full-scale and under real conditions as the test field was part of a road and a parking area. The permeable pavement alternatives were selected by Vikaune Fabrikker AS which is a manufacturer of permeable pavers. Vikaune Fabrikker also owns the test field which is still in operation. The test field is located at Sveberg outside Trondheim. The result from this project resulted in a better understanding of how permeable pavements handle water. We were also able to calibrate and validate models with acceptable accuracy. These models estimate the performance under different climate zones in Norway using historical weather data from 5 cities (Abdalla et al., 2021 and 2022). This project founded the basis for the new alternative pavers (ASAK Flyt).

Key researchers. Abbreviations used; SR (senior research scientist), R(research scientist)

- Edvard Sivertsen (SR, climate change, stormwater management and implementation of nature-based solution, 2008- present)
- Berit Time (chief research scientist, climate adaption of buildings, 1997- present)
- Gema S. Raspati (SR, technical performance, operation and maintenance of nature-based solution, 2012- present)
- Eli Sandberg (SR, climate change adaption, costs and insurance, 2018 - present)
- Stian Bruaset (senior business developer, long-term planning of urban water networks, 2008-present)
- Kamal Azrague (SR, water treatment using nature-based solutions, 2009 - present)
- Herman Helness (SR, integrated water management and sustainability assessment, 1991-present)
- Elhadi Abdalla (R, urban stormwater modelling, employed in 20% position, 2020- Feb. 2023, and in full-time from March 2023 to present)

Key contextual information:

- The use of NBS has from 2015 been subject to increasing attention world-wide, especially within the EU.

- The new Norwegian State planning guidelines for climate and energy planning and climate adaptation published in 2018 emphasize that nature-based solutions shall be used, and if not, it must be reasoned.
- The Planning and Building Act and the building code was 1. January 2024 revised to strengthen the focus on climate change adaption, the use of nature-based solutions and the three-step approach for stormwater management.

3. References to the research (indicative maximum of six references)

A selection of peer-reviewed publications:

Abdalla, E.M.H., I. Selseth, T. M. Muthanna, H. Helness, K. Alfredsen, T. Gaarden, E. Sivertsen (2021) Hydrological performance of lined permeable pavements in Norway. Blue-Green System 3 (1) 107–118; doi.org/10.2166/bgs.2021.009

Abdalla EMH, Muthanna TM, Alfredsen K & Sivertsen E (2022) Towards improving the hydrologic design of permeable pavements. Blue-Green Systems, 4 (2), pp 197-212; doi.org/10.2166/bgs.2022.004

Bosco, C, EMH Abdalla, TM Muthanna, K Alfredsen, B Rasten, H Kjennbakken, E Sivertsen (2023) Evaluating the Stormwater Management Model for hydrological simulation of infiltration swales in cold climates. Blue-Green Systems, 5 (2), 306–320; doi.org/10.2166/bgs.2023.044

Ganesh, H.R.R., Killingtveit, Å., Hung, C.R., Sandberg, E., Odd A. Tveit, Sivertsen, E. & Bjelle, E.L.: Aktiv flomdempning: Casestudie av Ilavassdraget i Trondheim kommune, VANN, 01, 58, 2023, 33-44, ISSN 0042-2592, https://vannforeningen.no/dokumentarkiv/aktiv-%EF%AC%82omdemping-case-studie-av-ilavassdraget-i-trondheim-kommune/

Hamouz, V., V. Pons, E. Sivertsen, G. S. Raspati, J.-L. Bertrand-Krajewski and T. M. Muthanna (2020) Detention-based green roofs for stormwater management under extreme precipitation due to climate change. Blue-Green Systems, 2 (1); doi.org/10.2166/bgs.2020.101

Raspati GS, Bruaset S, Azrague K, Ugarelli R, Muthanna TM, Time B & Sivertsen E (2023) Framework for documentation of nature-based solutions for stormwater management. Blue-Green Systems, 5 (2), p 135-151; doi.org/10.2166/bgs.2023.131

4. Details of the impact

The effect of climate change on the environment and economy is undeniable, and there has been a clear need to understand and implement nature-based solutions to minimise this effect. The knowledge building has mainly occurred through SFI Klima 2050 and spin-off projects in close collaboration with universities, research institutes, public and private sectors. SINTEF Community has had a pioneering role in defining, managing, and conducting the research.

We choose to categorise the impact of our research related to nature-based solutions in 3 main categories. The process from research to actual impact varies by category, and a short explanation for each category is given below, whereas a complete list of impacts for each category follows thereafter.

The impact through **knowledge transfer** has been realised through a series of projects with municipalities, where the overall objective has been to transfer knowledge into practical tools and

multidisciplinary collaboration processes. We have actively used community-of-practice as a work method to ensure this transfer.

The research results form a solid knowledge hub that has been actively disseminated and **transferred into new guidelines**. The communication strategy in the beforementioned projects has been that each scientific paper should also result in a Norwegian popular science article and at least one presentation at a conference targeting practitioners, preferably in Norwegian language, to maximise the impact. This communication strategy has resulted in rapid implementation of new research results. In this category we have also benefited from thematic meetings organised by Klima 2050, where researcher communicate directly with users, e.g. for the NBS example collection published by NVE (see below).

The development of **new NBS products and concepts** is a result of dedicated activities centred around one of five in-situ full-scale demonstration and documentation sites that has been established (see section 2 for details). Key in this work has been the active involvement of user partners as well as solution providers through pilot projects and thematic meetings.

i) Knowledge transfer targeting the public sector

- Implementation of NBS with Trondheim municipality (2020-2021)
- How to measure climate change adaptation with Network for climate change adaptation in Trøndelag (38 municipalities in Trøndelag county) (2020-2021)
- Testing indicators for climate change adaptation in Trondheim municipality (2022-2023)
- Measure climate change adaption with 10 municipalities in Vestland county (2021-2024)
- Sustainability of NBS with 7 municipalities and 5 private entities in Rogaland county (2021-2024)

ii) New guidelines

- Implementation of NBS, with check lists, to minimise climate change, made available at the homepage of the Directorate for the Environment (Miljødirektoratet).
- NBS example collection of climate adaption measures to handle stormwater at NVEs home page.
- Guideline for using permeable pavements made by the industry's umbrella organization betongfokus.
- NBS implementation guideline for Rogaland county.
- Documentation tool of NBS available at SINTEF book series (Bokhandel) – 2019.
- Guidelines for indicators for climate change adaptation for municipalities

iii) New NBS products and concepts

- **ASAK Flyt** was developed by ASAK Miljøstein and Snøhetta and the concept was launched autumn 2022. Asak FLYT is a new permeable system for stormwater management. There have been several commercial installations in Norway and the concept has gained considerable interests from abroad, e.g. Italy and USA.
- **Infiltration and detention in series solution** was developed in Klima 2050 and the first instalment was at Trondheim Town Square. The solution has been in operation since 2020.
- **Stormwater system combining permeable pavements, rain gardens and detention basin** was developed in Klima 2050 in connection to the ZEB Laboratory. The solution has been in operation since 2020.
- **Urbane Uterom** (detention-based roofs) is a concept developed by Storm Aqua, Skjævelandsgruppen, Leca, and Bergknapp. The concept is in commercial sale. Detention-

based roofs can be used on rooftops to detain rainwater before water is discharged to the stormwater network. The Urbane Uterom consist in principle of two layers, bottom layer inhibits the water detention quality whereas the top-layer consist of different materials such as sedum, grass or permeable pavers. The top-layer can be tailor-made to create urban outdoor spaces on rooftops for different uses and aesthetic qualities.

- **Tailor-made light-weight permeable paver** for roofs as part of Urbane Uterom (urbane outdoor space). Prototype demonstrated at Høvringen (2018-2021), yet not in commercial sale.
- **Tailor-made fraction of Filtralite** material (Leca Lettklinker) to maximise detention capacity developed by Leca. In commercial use.
- Patented **detention mat** for maximised detention developed by Isola. Prototype demonstrated at Høvringen, yet not in commercial sale.
- **Green swale** for managing road runoff. Greenswale has been in operation since 2020 by Skanska.
- **Alma Raingarden** developed by Storm Aqua between 2017-2019 is a pre-fabricated raingarden that can be used to handle runoff water from roofs and open spaces. It provides growth space for plants, and has internal storage capacity for water, which is useful for the plants in dryer periods. Alma Raingarden is in commercial sale.

5. Sources to corroborate the impact

- The Directorate for Building Quality (DIBK), which is responsible for climate adaption in Norway, has carried out climate and vulnerability analyzes for buildings in Norway through collaboration with SINTEF Community (Byggforsk).
- RCN shared Grethe Bergly's (CEO Multiconsult) recognition of Klima-2050: "*Our participation in Klima2050 became an important source of inspiration, to put climate adaptation on the agenda for our professional development. The support we have received from the researchers and duration over a long period of time has made it possible for us to offer innovative solutions in our projects*."
- ZEB Laboratory was the winner of the Government's award for Building quality in 2022, which had climate adaption as its focused theme.
- ASAK Flyt won the Fast Company's Innovation by Design Award 2023 . Ellen H. Schumann, Asak Miljøstein, talks about the new developed product, permeable paver; " *The system provides a unique possibility to make beautiful and creative outdoor pave which can handle huge amount of stormwater*."
- Rune Egeland, Skjævelandsgruppen AS: "*For us, as an industry player and supplier of detention-based roofs, Klima 2050 and the years of pilot testing have been very useful in product development, and we have been able to document the performance of our solutions*."
- Alma Regnbed (Skjævelandsgruppen AS) has been selected by the EU program BRIGAID in 2018 as one of six innovations to receive funding and expertise support for further development.
- Leca Lettklinker is demonstrated in many commercial projects. As an example, Økern portal in Oslo manage stormwater using this product among others.

Publication of cases
RCN plans to publish all impact cases in a separate evaluation report. By submitting the case the head of the administrative units consents to the publication of the case. Please indicate below if a case may not be made public for reasons of confidentiality.

If relevant, describe any reason to keep this case confidential:

The case is not confidential by itself, but a lot of the technical details which would accentuate the scientific merit of the solutions are. This is the nature of some of the industrial impact cases, industry requires confidentiality to some degree to protect their business and as a contract research institute, SINTEF must abide to that requirement. The more recent results are more confidential than older. The impact is however a very important contribution from SINTEF Digital.

SINTEF AS – SINTEF Digital 1

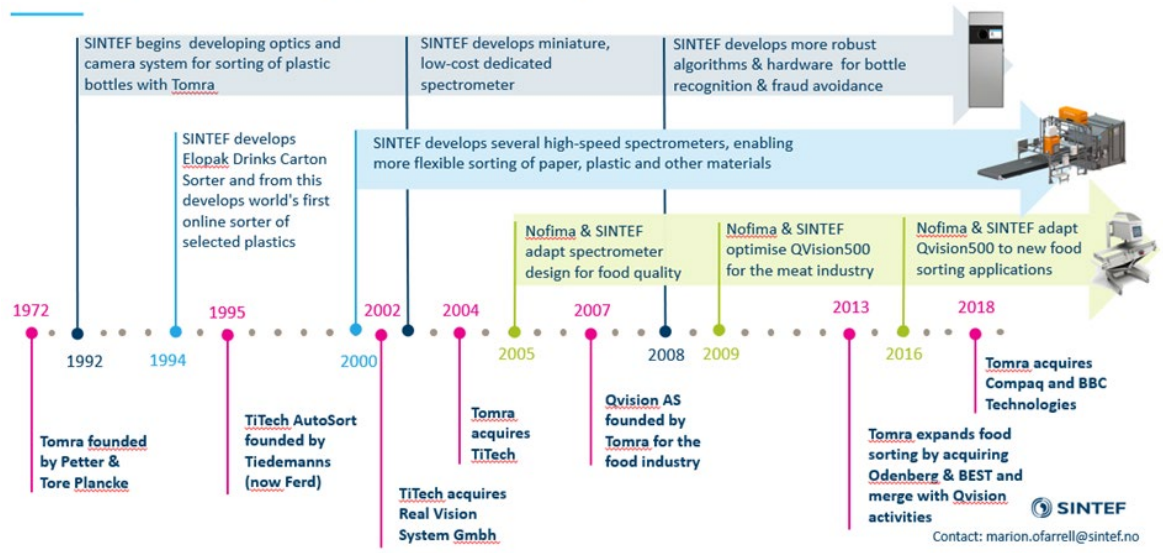
Institution: SINTEF
Administrative unit: SINTEF Digital
Title of case study: Tomra/Titech – reversing vending machines and automated sorting machines
Period when the underpinning research was undertaken: 1992-2024
Period when staff involved in the underpinning research were employed by the submitting institution: 1992-2024
Period when the impact occurred: 1992-2024

1. Summary of the impact (indicative maximum 100 words)

The last 30 years, SINTEF Digital has collaborated with Tomra within waste sorting. This work has a huge impact on sustainability considering the world generates 2 billion tons of municipal solid waste annually, and at least 33 percent of all plastic packaging ends up in nature. There are over 8,000 waste sorting machines and 82,000 reverse vending machines globally based on our technology. These are sorting approximately 10,000 truckloads of garbage each working day and 45 billion beverage containers each year. This amounts to a stunning 10 million tons of recycled plastic each year. The most recent contributions within the evaluation period are on Tomras Flow technology, the Autosort Flake sorting machines and on the high-precision spectrometers.

2. Underpinning research (indicative maximum 500 words)

SINTEF Digital has over a 30-year period operated as a virtual R&D department for Tomra, one of Norway's major tech companies with an annual revenue of about 1 billion EURO. This includes a series of projects supported by the Norwegian Research Council, but also direct research for Tomra without governmental support. The figure below provides an overview over the main collaboration since 1992.



SINTEF Digital started working closely with Tomra in the early 1990s and developed the basic optics and camera system for sorting of plastic bottles in **reverse vending machines**. These are difficult objects to image as they are transparent, but by R&D on a solution for confocal imaging by utilising Fresnel lenses, beam splitters and mirrors, Tomra could implement a low-cost solution in their reverse vending machines in 1992. SINTEF Digital also worked on recognition algorithms based on robust statistics and matching algorithms which were able to recognise beverage containers which could only partly be imaged due to the cap and torn-off stickers etc. More recently SINTEF Digital has worked with even more robust recognition algorithms, robust low-resolution reading of barcodes, fraud detection and dirt detection, some of these technologies are implemented in the more recent Flow technology concept introduced by Tomra in 2013 in the T-9 series of reverse vending machines with a much more compact design. In parallel SINTEF Digital did R&D on miniature, low-cost dedicated spectrometers based on patented diffractive optical elements for reverse vending in 2002, a component which SINTEF Digital produces for Tomra with the latest cleanroom semiconductor production technologies.

The world's first complete system for **high-capacity garbage sorting** was developed by SINTEF Digital in 1995 with TiTech Autosort as the customer aimed at sorting plastic coated beverage cartons and certain plastics/polymers from a waste stream, which was later extended by R&D on several high-speed scanning spectrometer designs in 2000 for sorting all major types of plastics/polymers, paper fractions and other materials. Autosort was acquired by Tomra Sorting in 2004. Several of SINTEF Digital's research groups have been and are still heavily involved in the design and development of the core technology of their spectral imaging technology used to image and sort waste into fractions. SINTEF Digital has also developed electromagnetic detection and X-ray detection techniques for different types of ore, metal fractions and food sorting for Tomra. In the past 10 years, we have worked on increasing the spatial resolution and scanning width of AutoSort, and this resulted in the new product, AutoSort Flake in 2016.

Based on the spectrometers for polymer sorting, SINTEF Digital and the food research institute Nofima adapted these for **food sorting** purposes from 2005 and onward, QVision500 was introduced to the meat industry in 2009 with the aim of sorting minced meat, but has also been applied to a range of different other food products. The main research was on optimal resolution and calibration of light spectra for robust measurement of ingredients like fat, water and proteins and adaption to different food products. SINTEF Digital and Nofima has also developed single point

spectrometers for measuring the core temperature of sausages and liver paste, as well as muscle fiber measurements of tenderness in meat based on x-ray technology 2014-2016 (cf. publications 1 & 2 below). Key partners have been Tomra and various food manufacturers.

- Jon Tschudi, senior research scientist, has since 1995 worked with all the high-speed scanning spectrometers, as well as the food sorting spectrometers (Research Gate profile).
- Marion O'Farrell, research manager and senior research scientist, has worked with applied spectroscopy for food applications both in the x-ray and infrared domain (Google Scholar profile).
- Trine Kirkhus, senior research scientist, headed several projects on fraud detection and image recognition algorithms (Research Gate profile).
- Gregory Bouquet, senior research scientist, has worked with x-ray spectroscopic systems for Tomra (Google Scholar profile)
- Kari Anne Hestnes Bakke, senior research scientist, has worked with high-speed and high-accuracy scanning spectrometers and application-specific data analysis (Research Gate profile).
- Karl Henrik Haugholt, senior research scientist, worked on the Flow technology concepts for Tomra (Research Gate profile).
- Alain Ferber, senior research scientist, worked with electromagnetic detection of ore and x-ray spectroscopic measurements (retired 2023) (Research Gate profile).
- Ib-Rune Johansen, chief scientist and research manager, was the inventor of the diffractive optical elements as well as other microoptical components and worked as project manager for several projects developing this technology for use in reverse vending machines (Ib-Rune left SINTEF 2014 for Tunable, a spin-off company from SINTEF) (Research Gate profile)
- Odd Løvhaugen, senior research scientist, was inventor of the diffractive optical elements and worked on several waste sorting projects for Tomra, including polymer and carton sorting (retired 2015).
- Tom Kavli, chief scientist, worked on the Fresnel lens systems and robust bottle recognition projects from 1992 until he left SINTEF in 2011 for a position at Elliptic Labs (Research Gate profile).
- In addition to these main contributors, there are several other researchers that has contributed, both from SINTEF Digital and SINTEF Industry

3. References to the research (indicative maximum of six references)

Since much of this research has been industrial applied research with business-sensitive information, there are a lot of unpublished scientific outputs which has been implemented. However, one of the solutions from the period 2012-2022 is patented and is hence in the public domain:

Patent WO2012177149: Tom Kavli (SINTEF), Geir Sæther (TOMRA), Johnny Njåstad (TOMRA); Method and Apparatus for Detecting Fraud Attempts in Reverse Vending Machines https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2012177149

Some of the food applications related to the research for Tomra have also been published:

1. **O'Farrell, Marion; Bouquet, Grégory; Tschudi, Jon; Bakke, Kari Anne Hestnes**; Egelandsdal, Bjørg; Lunde, Kathrine. Measuring water holding capacity—A comparison between a miniature near infrared system and an energy dispersive X-ray scattering system. NIR news 2014, Volume 25 (3), pp. 11-14. https://doi.org/10.1255/nirn.1435
2. Zhu, Han; **O'Farrell, Marion; Bouquet, Grégory**; Lunde, Kathrine; Egelandsdal, Bjørg; Alvseike, Ole; Berg, Per; Gjerlaug-Enger, Eli; Hansen, Eddy Walther. Evaluating nuclear

magnetic resonance (NMR) as a robust reference method for online spectroscopic measurement of water holding capacity (WHC). Journal of Food Engineering 2016, Volume 175, pp. 51-57. https://doi.org/10.1016/j.jfoodeng.2015.12.003

3. Wold, Jens Petter; **O'Farrell, Marion**; Andersen, Petter Vejle; **Tschudi, Jon**. Optimization of instrument design for in-line monitoring of dry matter content in single potatoes by NIR interaction spectroscopy. Foods 2021, Volume 10 (4), pp. 1-14. https://doi.org/10.3390/foods10040828

The basic methodology of the applied research on inline spectroscopy has also been published:

4. **Tschudi, Jon; O'Farrell, Marion; Bakke, Kari Anne Hestnes**. Inline spectroscopy: From concept to function. Applied Spectroscopy 2018, Volume 72 (9), pp. 1298-1309. https://doi.org/10.1177/0003702818788374

4. Details of the impact (indicative maximum 750 words)

"SINTEF Digital is a key research partner for us in developing world-class, sensor-based sorting solutions. We have been working with them for more than 20 years in an extremely successful way." – Volker Rehrmann, Executive Vice President and CTO, Head of TOMRA Sorting Solutions.

SINTEF Digital has contributed to TOMRA within mainly four different fields:

Reverse Vending Solutions where SINTEF Digital has contributed with dedicated spectroscopy, camera system design and data analysis for sorting of plastic bottles and beverage cans. Reverse vending solutions are applied in markets with a deposit refund system for beverage containers and in some markets, there are more than a hundred different variants of beverage containers in the market with a refund. Fraud detection is important to avoid scammers the possibility to infringe on the deposit refund systems, so SINTEF Digital has contributed a lot to avoid fraud. Most recent contributions with impact have been on the Flow technology which was introduced in 2014 (). There are currently 82,000 installations in 60 different countries. Deposit refund systems drastically reduce the littering caused by 1.4 trillion beverage containers used in the world each year since the refund provides an incentive for recycling the bottles and cans. Tomra writes "There is an estimated 5.25 trillion pieces of plastic debris in the oceans. If this continues, by 2050, the amount of plastic in the ocean will outweigh the fish. Of the 78 million tons of plastic packaging produced every year, only 14% is collected for recycling. Crucially, only 2% of all the world's plastic

packaging is recycled in a “closed loop”, where material can be used for the same or similar kind of packaging once again. 86% of plastic packaging currently ends up in landfills and incinerators, or as litter." More information is available at this web site.

Waste sorting machines where SINTEF Digital has contributed with high-speed dedicated spectrometer design and data analysis for large volume belt sorting. The capacity of one such machine is typically belt speeds of 2-10 m/s and several tonnes of municipal waste per hour. These are typically used for municipal waste for cities with several 100.000 inhabitants at centralized sites. One machine typically sorts out one particular fraction and is capable of distinguishing between all the 7 major polymer/plastic types or distinguish carton from different paper qualities. The cleaner and more uniform fractions one is able to sort, the higher value the material has for recycling, so accuracy is of vital importance. About 8.000 of these sorting machines are in use world-wide contributing to a stunning 10 million tonnes of plastic sorted every year. The most recent contribution to impact has been on the flake sorters which were introduced in 2019 (https://www.tomra.com/en/waste-metal-recycling/products/machines/autosort-flake and https://www.tomra.com/en/waste-metal-recycling/products/machines/innosort-flake). More detailed information about waste sorting is available at web site.

Food sorting machines where SINTEF has contributed with high-accuracy spectrometer design and geometry, as well as quantitative data analysis and calibration in collaboration with NOFIMA. Belt speeds are slower, but accuracy and geometry are of vital importance, combined with calibration, to measure the key parameters of the food products which are typical water content, fat and proteins. After the initial work on the QVision spectroscopy-based machines, Tomra acquired BEST and Odenberg with a colour and laser-based sorting systems. More detailed information is available at this web site.

Mining sorting machines where SINTEF has contributed to high-speed electromagnetic and x-ray detection of ore. The main challenge in this domain is energy consumption for mining the ore and identifying in which parts of the ore which are valuable. By identifying the content-rich ore Tomra helps the mining companies to minimizing waste and environmental impact, while maximizing the efficiency of the operation. More detailed information is available at this web site.

5. Sources to corroborate the impact (indicative maximum of ten references)

https://www.tomra.com/

https://www.foodnavigator.com/Article/2018/10/19/SmartSensor-promises-better-quality-control-for-higher-profits#
https://www.sintef.no/en/latest-news/2015/x-ray-scanning-to-guarantee-meat-tenderness/
https://www.sintef.no/en/latest-news/2018/have-you-heard-about-piezomems-technology/

Impact case guidelines

Each case study should include sufficiently clear and detailed information to enable the evaluation committee to make judgements based on the information it contains, without making inferences, gathering additional material, following up references or relying on members' prior knowledge. References to other sources of information will be used for verification purposes only, not as a means for the evaluation committee to gather further information to inform judgements.

In this evaluation, impact is defined as an effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia.

Timeframes

- The impact must have occurred between 2012 and 2022
- Some of the underpinning research should have been published in 2012 or later
- The administrative units are encouraged to prioritise recent cases

Page limit

Each completed case study template will be limited to **five pages** in length. Within the annotated template below, indicative guidance is provided about the expected maximum length limit of each section, but institutions will have flexibility to exceed these so long as the case study as a whole remains no longer than **five pages** (font Calibri, font size 11). Please write the text into the framed template under the sections 1–5 below. The guiding text that stands there now, can be deleted.

Maximum number of cases permitted per administrative unit

For up to 10 researchers: one case; for 10 to 30 researchers: two cases; for 30-50 researchers: three cases; for 50-100 researchers: four cases, and up to five cases for units exceeding 100 researchers.

Naming and numbering of cases

Please use the standardised short name for the administrative unit, and the case number for the unit (1,2,3, etc) in the headline of the case. Each case should be stored as a separate PDF-document with the file name: [Name of the institution and name of the administrative unit] [case number]

Publication of cases

RCN plans to publish all impact cases in a separate evaluation report. By submitting the case the head of the administrative units consents to the publication of the case. Please indicate below if a case may not be made public for reasons of confidentiality.

If relevant, describe any reason to keep this case confidential:

SINTEF AS – SINTEF Digital

Institution: SINTEF
Administrative unit: SINTEF Digital
Title of case study: Case 1 – MRST (transforming research on reservoir simulation)
Period when the underpinning research was undertaken: 2006–2024
Period when staff involved in the underpinning research were employed by the submitting institution: 2006–2024
Period when the impact occurred: 2009–2024, continuous period, dates difficult to pinpoint

1. Summary of the impact (indicative maximum 100 words)

Since 2009, SINTEF Digital has consistently pioneered the release of high-quality open-source code, widely embraced globally for research and simulations in porous media flow modelling. Commercial reservoir simulators in the industry remain proprietary and closed source. The complexity of these simulators is such that only a select few research groups possess the stamina and capability to develop such intricate programs independently. Through the MATLAB Reservoir Simulation Toolbox (MRST), SINTEF has democratized state-of-the-art technology, providing a platform for rapid prototyping and demonstration in a relevant environment. This transformation has significantly accelerated research and innovation and influenced others to do the same.

2. Underpinning research (indicative maximum 500 words)

MRST started as a research code for consistent discretizations and multiscale methods for incompressible flow but has gradually developed into a general research platform offering industry-grade capabilities.

On one hand, MRST represents an amalgamation of prototype implementations of new simulation technology developed for specific clients or purposes, alongside implementations of standard methods and models to enable the research of new technologies and their subsequent validation in a relevant environment. On the surface, a lot of the standard technology is well known, but has proven time-consuming and difficult to reproduce accurately in practice in full concert. Altogether, MRST is not the result of a carefully planned development but rather the cumulative byproduct of research on computational methods conducted in projects supported by public and private funding. As a result, MRST is brimming with a diverse set of models and methods that represent, or at the point of their first release represented, the research front in the field. Reviewing the research insights or findings that underpin the more than 65 modules that currently make up the software and providing details of the research undertaken by our group and third-party contributors, is not possible within a 500-word limit.

The other way to see MRST is as a research product in its own. It is widely acknowledged that computer code is a vital aspect of the scientific record, often containing intricate details not covered in papers, despite the authors' efforts to describe their method or idea thoroughly. Publishing full code therefore supports the important principle of reproducible research. However, just providing a code is not generally sufficient to enable others to easily leverage your results and insights and use them to do science (or make policy decisions). We have devoted significant research and a lot of experimental programming into developing flexible data structures and library functions and efficient tools for rapid prototyping and establish standards for how to implement new ideas so that they are accessible and simple to understand. A key to this was our research into automatic differentiation for partial differential equations and its application in differentiable simulators, ongoing since late 2013. Equally important, much effort has gone into verifying and validating new ideas in an industry-relevant environment and maturing them into efficient, flexible, and robust

simulation technology that can be credibly used by others to conduct research for new problems and in new settings.

A large and complex software system like MRST can admittedly appear overwhelming to newcomers. However, we believe that our novel automatic-differentiation, object-oriented simulator (AD-OO) framework and the modular and interoperable design of the overall ecosystem, researched and refined over the years, along with the comprehensive documentation and tutorials that follow the software, are key to its widespread adoption and international success.

Key researchers contributing to MRST:

- **KA Lie**: chief scientist, founder of MRST, strategic leadership, quality assurance, worked on most parts except geomechanics, dissemination, developed educational material and most tutorials. Elected SIAM Fellow in 2020 for work done on and with MRST.
- **J Aarnes:** research scientist, precursor code, elliptic discretizations, multiscale methods, grid coarsening, etc. (Left SINTEF in 2007)
- **S Krogstad:** senior scientist, precursor codes, multiscale, discretizations, coarsening, wrote first version of automatic differentiation and industry-grade simulator (ad-fi), adjoints and optimization, industry-grade flow physics, well models, model reduction, etc.
- **B Skaflestad:** research scientist, turned precursor code into toolbox, input processing, release manager, ecosystem, code wizard, testing/quality assurance, multiscale, coarsening, etc.
- **JR Natvig:** research scientist, grid processing, transport solvers, multiscale, coarsening, etc. (Left SINTEF in 2012; developer of multiscale INTERSECT, cf. impact in point 4).
- **HM Nilsen:** senior scientist, first CO2 simulators, worked on almost all types of flow and mechanics solvers, remarkable ability to stress-test and find/correct errors. (Joined 2007)
- **O Møyner:** senior scientist, started with multiscale, worked on almost all aspects, main architect for AD-OO simulator framework and differentiable solvers, release manager, documentation, tutorials, etc. (Joined in 2012). Awarded the SIAM Geosciences Early Career award in 2019 for work done and with MRST.
- **X Raynaud:** senior scientist, verifying ad-fi, discretizations and solvers, mechanics, EOR, injectivity, multi-models, etc. Main architect of BattMo, built on top of MRST. (Joined in 2012)
- **O Andersen:** senior scientist, first version of CO2 trapping, co2lab, mechanics, geothermal, etc. (Joined in 2011)
- **ØA Klemetsdal:** research scientist, discretizations, multiscale, adaptive coarsening, nonlinear solvers, geothermal, test suite, etc. (Joined in 2016)
- **F Watson:** research scientist, CO2 laboratory, flow diagnostics, BattMo extension, quality assurance, dissemination, and release manager. (Joined 2018)

Many other researchers from SINTEF Digital have made numerous contributions to the software.

The official release of MRST contains third-party contributions from University of Bergen, NTNU, Heriot-Watt, TU Delft, NORCE, MIT, Louisiana State University, Stanford, GEUS, China University of Petroleum, Montanuniversität Leoben, etc. In the latest release (MRST 2023b), 20 out of 65 add-on modules have either been developed externally or have significant external contributions. In addition, you can find less polished modules and various MRST codes in repositories on the web.

Given MRST's primary role as a research platform for SINTEF Digital, numerous in-house modules and add-ons have been delivered to clients, details of which remain confidential.

- **References to the research** (indicative maximum of six references)

The software itself:

- Website: mrst.no
- GitHub: github.com/SINTEF-AppliedCompSci/MRST

Journal article and textbooks (all open access):

- K.-A. Lie, S. Krogstad, I. S. Ligaarden, J. R. Natvig, H. M. Nilsen, and B. Skaflestad. Open source MATLAB implementation of consistent discretisations on complex grids. *Comput. Geosci.,* Vol. 16, No. 2, pp. 297-322, 2012. DOI: 10.1007/s10596-011-9244-4
- K.-A. Lie. An Introduction to Reservoir Simulation Using MATLAB/GNU Octave: User Guide to the MATLAB Reservoir Simulation Toolbox (MRST), Cambridge University Press, 2019. URL: www.cambridge.org/9781108492430. DOI: 10.1017/9781108591416
- Advanced Modelling with the MATLAB Reservoir Simulation Toolbox. Edited by K.-A. Lie and O. Møyner. Cambridge University Press, September 2021. DOI: 10.1017/9781009019781

Not open access:

- S. Krogstad, K.-A. Lie, O. Møyner, H. M. Nilsen, X. Raynaud, and B. Skaflestad. MRST-AD - an open-source framework for rapid prototyping and evaluation of reservoir simulation problems. 2015 Reservoir Simulation Symposium, Houston, Texas, USA, 23-25 February 2015. DOI: 10.2118/173317-MS. URL: folk.ntnu.no/andreas/papers/rss15-mrst.pdf

4. Details of the impact (indicative maximum 750 words)

Notice: the following must be considered a continuous activity, for which exact dates are difficult to pinpoint.

MRST was developed as a research tool for SINTEF Digital and has been used to research new ideas for many clients and turn them into technologies demonstrated in a relevant environment (considered sufficient to warrant subsequent reimplementation in an operational environment). Examples of technologies that have been deployed operationally and had a commercial impact:

- multiscale formulations powering SLB's INTERSECT multiscale sequential fully implicit simulator (SINTEF also developed an early multiscale solver in the ECLIPSE FrontSim streamline simulator);
- novel model-reduction tools based on hierarchical and flow-based coarsening powering in-house software tools at ExxonMobil for field planning and reservoir management;
- flow diagnostics tools implemented in-house by Chevron and ExxonMobil and available through ResInsight, the rapid reservoir modelling (RRM) software;
- tools for estimating trapping in carbon storage were converged to predict urban flooding and effects of torrential rain and included in what is today AutoDesk Forma.

However, the biggest impact of MRST comes through its uptake as ***a go-to research platform*** for the international research community on modelling and simulation of porous media flow, its **impact on education**, and its ***pioneering role in use of open source to accelerate innovation***.

Tracing the use of a software that is given away for free is difficult. However, the widespread use of MRST is indicated by its numerous ***downloads*** (almost 20.000 unique from Sept 2021 to Sept 2023), its relatively active ***user forum*** (200+ unique conversations in 2023), and the attendance at the ***two MRST Symposia:*** 190+ registered in 2023, 169 in 2021. (Fun fact: MRST has for years been the largest generator of traffic on SINTEF's website.)

The importance of MRST as a research platform is corroborated by its inclusion in external scholarly works, reported in §5 of this document; altogether more than ***670 scientific papers*** and ***270 master and doctoral theses***. The consistent feedback is that the software is an effective research platform that enables researchers to leverage advanced and well-proven functionality it would otherwise have taken years to develop. This is particularly critical for master and PhD students. Beyond this, the exact use in education is more difficult to trace. We know both explicitly and by word of mouth that MRST is used both systematically and intermittently in teaching and student supervision at numerous universities worldwide; see, e.g., youtube.com/watch?v=RuHzJ54kZ_s for a discussion of its use at Heriot Watt. Similar stories exist for China University of Petroleum, Texas A&M, etc.

Moreover, the 450–3500 monthly full-text views reported consistently by the publisher of the first textbook serves as a reliable indicator of MRST's popularity.

In contrast to larger research areas, reservoir simulation is relatively niche, with major conferences drawing only a few hundred attendees. Considering the potential audience size, MRST can be deemed widely adopted in this field that has a huge impact on energy supply, economic growth, and environmental sustainability.

When first released, MRST was the first of its kind. By its high software quality and flexibility that few others match, MRST has played a pioneering role in dispelling skepticism towards open source prevalent within the petroleum engineering industry (and academia) a decade ago. We may just have been lucky to adopt an emerging trend, but many have followed suit, embracing open source. Experience with developing and releasing MRST also played a pivotal role in our decision, nearly 15 years ago, to collaborate with Equinor and NORCE in creating OPM Flow, the world's first operational open-source-based reservoir simulator, now actively employed on the Norwegian Continental Shelf. MRST's success has also been credited with inspiring subsequent open and independent developments at institutions such as TU Delft and the University of Bergen.

MRST has inspired new generations of SINTEF software like BattMo for continuum modelling of electrochemical devices (built upon MRST), GPU Ocean for simplified ocean modelling, IFEM for coupled structural and fluid mechanics, Jutul for differentiable simulators, and SWIM for surface water and urban flooding, etc.

How did MRST establish its influential role? Code quality, access to both research-front and industry-grade functionality, scholarly publication, and careful documentation are important factors. However, an extensive set of educational tutorials and a forthcoming strategy towards users also helped. Last, but not least, by not only teaching the physics, mathematics, and numerics of flow in porous media, but also showing how to implement the models and algorithms in a robust and efficient manner, the first MRST textbook seems to have filled a hole in the market. This has been a clear strategy from day one: if people find a software tool useful during education, they are likely to want to use it later in life.

5. Sources to corroborate the impact (indicative maximum of ten references)
(Incomplete) lists of scientific literature based on MRST by people external to SINTEF Digital:

- Journal papers (431): sintef.no/projectweb/mrst/publications/papers-by-others/
- Conference papers (243): sintef.no/projectweb/mrst/publications/proceedings-papers/
- Master theses (161): sintef.no/projectweb/mrst/publications/master-theses/
- Doctoral theses (108): sintef.no/projectweb/mrst/publications/phd-theses/

The entries in these lists are either taken from automatic Google Scholar feeds of scientific work that either cite our foundational paper or the textbooks or that explicitly state that they use the software. Some entries have also been supplied by the authors themselves or their colleagues. We have reason to believe that the list of master theses is (far) too short as many universities do not publish these online.

In addition, SINTEF Digital has published many papers using MRST as a key research tool:

- Journal papers (86): sintef.no/projectweb/mrst/publications/papers-by-mrst-team/
- Conference papers (70): sintef.no/projectweb/mrst/publications/proceedings-by-mrst-team/

Out of the 86 journal papers, 28 are in level-2 journals in the Norwegian publication system.

SINTEF Digital [case #3]

Institution: SINTEF
Administrative unit: Digital
Title of case study: Mental health services research
Period when the underpinning research was undertaken: 2012-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2012-2022
Period when the impact occurred: 2012-2022

1. Summary of the impact (indicative maximum 100 words)

SINTEF Digital has long experience in mental health services research. Topics cover characteristics and development of services at different levels of specialisation, resource use, service utilisation, care pathways, mechanisms for coordinating and integrating care, and patient/care recipients' experiences. Our main contribution is related to development of Norwegian health policy and health services. Many of our projects are commissioned by Norwegian health authorities. Our research has produced impact through different data/outputs:

- Data for planning and management
- Research-based insights and recommendations for service and policy development
- Mental health services in the municipalities are planned based on insight from our project
- The national implementation of pathways for mental health and substance abuse was put to a stop and changed as a result of our evaluation

2. Underpinning research (indicative maximum 500 words)

Mental health services research in SINTEF Digital has for more than 40 years provided national, regional, and local decisions- and policymakers, and service providers with crucial data, knowledge and evidence on resource use, service use and accessibility, patient pathways, care coordination, patient experiences, service quality and more, to inform public policymaking, implementation, and audit. Our research is multidisciplinary and covers quantitative and qualitative methods, and often involves method triangulation. We perform both commissioned and researcher-initiated research.

The commissioned research dates back to the 1980s. From 1979 until 2013 Health Services Research at SINTEF Digital (formerly Norwegian Institute of Hospital Research) surveyed patients in specialised mental health services every fifth year ('the patient mapping study'). From the late 1980s, SINTEF Digital collected service-use and -experience data on patients discharged from specialised healthcare, which later became the Norwegian Patient Registry (NPR) (that was transferred to the Directorate of Health from 2007). These long-lasting, large-scale projects paved the way for an extensive register-based research effort within the field of mental health services research. In the 2012-2022 period, we have three projects for the Norwegian Directorate for Health: (i) the final tranche of the patient mapping study, (ii) a series of projects (that began in 2007) collecting annual data on personnel and other key information on mental health services in the municipalities, in charge of long-term care, primary care, and social and welfare services, and (iii) a national survey on patient and user experiences with outpatient mental health services.

Evaluation of new health service initiatives is a second line of commissioned research. The eight evaluations undertaken in the 2012-2022 period cover evaluations of policy and service initiatives related to work participation and return to work for people with health issues (including mental

health), models and methods of service delivery, patient pathways, service collaboration, and coordination. These have been mainly commissioned by national health authorities. The commissioned research in this period also includes eight other research projects on organisation of low-threshold services, service use and (lack of) collaboration between services, mental health services (or lack of) for children and youth under the care of child welfare services, and on policies and efforts for suicide prevention.

Our researcher-initiated research in the period 2012-2022 include four projects funded by the Research Council of Norway on common mental disorders and disability pension, and projects on patient pathways for different patient populations, including people with long-term mental illness, young adults, and those who are victims to or bereaved by suicide. In this period, we have participated in and been WP-leaders in four EU-funded projects with partners from many European countries, on (i) financing systems' effects on the quality of mental health care in Europe, (ii) integrated care for people with chronic diseases (with mental health as one case), (iii) psychiatric re-hospitalisation, and (iv) welfare state impact on mental wellbeing among the "oldest old" populations. Researcher-initiated project also involve innovation projects, most notably one on use of virtual reality to help people struggling with severe mental health issues and are living social isolated lives.

Key researchers, all currently working in SINTEF Digital (link to personal webpage from their name): Marian Ådnanes, senior researcher 2012-13 and 2021-22. Research manager 2013-2021. Solveig Osborg Ose, senior researcher, Jorid Kalseth, senior researcher, Silje L. Kaspersen, researcher (2012-2018, senior researcher 2018-), Eva Lassemo, researcher (2012-2021, senior researcher 2021-), Jannike Kaasbøll, researcher 2017- and Kristin Thaulow, researcher 2019-.

This research area involves broad national and international collaboration and networks including user organisations in mental health, service providers, other research institutes, and universities in Norway (i.e., NTNU, Akershus University hospital, Norwegian Institute of Public health (FHI), University of South-Eastern Norway, Regional Centre for Child and Youth – Mental Health and Child Welfare, NTNU Samfunnsforskning, the Work Research Institute (AFI)) as well as the National competence centre for mental health work (NAPHA). Internationally, we have collaborated with i.e., University of Oxford, University of Verona (Italy), London School of Economics and Political Science (UK), Åbo Akademi University (Finland), The Autonomous University of Madrid (Spain), University of Canberra (Australia), IESE Business School (Spain), The Finnish Institute for Health and Welfare (THL), and International Foundation for Integrated Care (IFIC).

3. References to the research (indicative maximum of six references)

Our mental health services research has produced a huge number of outputs in the period, including scientific reports and about 50 peer-reviewed scientific articles involving members of the key researcher team still working in SINTEF. Below we have listed six scientific articles as examples of our research:

Ose, S. O., Tveit, T., & Mehlum, L. (2021). Non-suicidal self-injury (NSSI) in adult psychiatric outpatients–A nationwide study. *Journal of psychiatric research*, *133*, 1-9. https://doi.org/10.1016/j.jpsychires.2020.11.031

Ådnanes, M., Cresswell-Smith, J., **Melby**, L., Westerlund, H., Šprah, L., Sfetcu, R., ... & Donisi, V. (2020). Discharge planning, self-management, and community support: Strategies to avoid psychiatric rehospitalisation from a service user perspective. *Patient Education and Counseling*, *103*(5), 1033-1040. https://doi.org/10.1016/j.pec.2019.12.002

Gutiérrez-Colosía M R, Salvador-Carulla L, Salinas-Pérez J A, García-Alonso C R, Cid J, Salazzari D, Montagni I, Tedeschi F, Cetrano G, Chevreul K, **Kalseth** J, Hagmair G, Straßmayr C, Park A L, Kalseth B, Amaddeo F and For the REFINEMENT Group (2017). Standard comparison of local mental health care systems in eight European countries. Epidemiology and Psychiatric *Sciences*, 1-14. https://doi.org/10.1017/S2045796017000415

Lassemo, E., Sandanger, I., Nygård, J. F., & Sørgaard, K. W. (2017). The epidemiology of post-traumatic stress disorder in Norway: trauma characteristics and pre-existing psychiatric disorders. *Social psychiatry and psychiatric epidemiology*, *52*, 11-19. https://doi.org/10.1007/s00127-016-1295-3

Kalseth, J., **Lassemo**, E., Wahlbeck, K., Haaramo, P., & Magnussen, J. (2016). Psychiatric readmissions and their association with environmental and health system characteristics: a systematic review of the literature. *BMC psychiatry*, *16*, 1-9. https://doi.org/10.1186/s12888-016-1099-8

Kaspersen, S. L., Pape, K., Ose, S. O., Gunnell, D., & Bjørngaard, J. H. (2016). Unemployment and initiation of psychotropic medication: a case-crossover study of 2 348 552 Norwegian employees. *Occupational and environmental medicine*, *73*(11), 719-726. https://doi.org/10.1136/oemed-2016-103578

4. Details of the impact (indicative maximum 750 words)

Our research impacts through research-based knowledge and recommendations to authorities and other decision-makers to e.g. plan services, examine whether targets in action plans have been reached, and evaluate reforms. Research may influence legislatures, governments or judiciaries, or other public bodies at an international, national, regional, and local level. Other users are professional associations, Non-Governmental Organisations (NGOs) and the voluntary sector. The beneficiaries are diverse, including patients and their families, medical and other professionals, or society more broadly. Improving the mental health of the population through improved accessibility, efficacy and quality of mental health services, benefits the society at large in terms of reduced health care costs, increased work participation and productivity, reducing mental health and substance abuse related crime rates, enhanced social inclusion, and improving general health outcomes. The research may impact *directly* by providing necessary data and knowledge foundation for decision making, or *indirectly* by impacting on public debate, or via other stakeholders. Providing supporting evidence of the impact is often difficult, for a variety of reasons. There are many and often complex channels of influences, some are open and can be documented but more often research informs policy in a less open manner, without being referred to. Therefore, it is a challenge to provide clear evidence and metrics of impact of strands of our research. We provide a narrative of the impact for a selection of projects below, influencing policy and services at different levels.

Our municipal mental health and substance abuse work includes a long-term project covering prevention, treatment, rehabilitation, follow-up, and harm reduction. Since 2007, SINTEF Digital has been responsible for the annual collection of data from all Norwegian municipalities, documenting resource use, competencies, and structuring of these services. These findings are compiled in an annual report that also summarises national guidelines and policies, as well as national and international research. This is a very influential project as a source of information and knowledge informing planning and policy development. The annual reports are referenced in the national budgets annually, in a long list of Official Norwegian Reports, white papers, action plans, etc., on for instance (by Google translate from Norwegian), foster home care; children being exposed to violence, sexual abuse and neglect; reform of the treatment and follow-up of people

with substance abuse problems and addiction; priority setting in the health and care service; white paper on the development of primary healthcare service for the future; and national health and hospital plan. The results are often referred to in the Parliament in debates, as parliamentary questions, interpellation, Private Members' Motion, and comments on consultation papers. The results are also used by, amongst others, the National Competence Centre for Mental Health Work in their dialogue with municipalities and in their courses. It is also used as recommended knowledgebase in, for instance, the guidelines for the development of municipal action plans against violence in close relationships.

SINTEF Digital evaluated the introduction of care pathways ("pakkeforløp") within specialist mental health and substance abuse treatment services in 2019. The goal was to improve services by focusing on user participation, coordinated patient flow, reducing waiting time, improving equal access to services, and increased emphasis on physical health and lifestyle. The purpose of the evaluation was to understand how the care pathways was experienced by the various actors, and to obtain knowledge about whether the care pathways meet the intentions. The health authorities use the evaluation to adjust the care pathways and improve the quality of the services. The evaluation results (documented in reports in 2020 and 2021) revealed challenges with the introduction of the pathways and raised several critical issues; e.g., that the care pathways only to a little extent contributed to improved coordination, and that the users were not sufficiently informed and involved in their treatment processes. The reports received considerable interest for instance from the Norwegian Association for Psychologists, user organisations and other interest groups. It also attracted significant media attention, e.g. in the most watched radio/TV daily debate programme "Dagsnytt 18". Based on the first report, the Minister of Health and care services at that time made a list of demands for the regional health authorities and the Directorate of Health. After the second report, the health authorities decided to change the name from care pathways (or directly translated from Norwegian "package pathways") to National Patient Pathways and to continue to develop them. Our evaluation found that many professionals perceived the term "pakkeforløp" as negative and avoided using the term out of consideration for patients and users. The change was implemented from 1. January 2023 and was a direct result of our evaluation. To further develop the National Patient Pathways, the health authorities chose to terminate the evaluation. Instead, SINTEF Digital was engaged to perform a national user survey among users and patients in outpatient clinics in mental healthcare and drug treatment services, which is now being undertaken.

5. Sources to corroborate the impact (indicative maximum of ten references)
Vi include firstly sources that corroborate the impact on policy of the two projects described in point 4.

Project IS-24/8

The data from the project constitute the official data on resource use and other characteristics of municipal mental health and substance abuse work. The importance of the project for planning, policy and service development for national health authorities is corroborated by the following quotation from The Directorate of health:
"IS-24/8 is a central management tool for the Norwegian Directorate of Health, the Ministry of Health and Care Services (HOD), and the county governors within municipal mental health and substance abuse work, based on our respective societal missions, both at the national, regional, and local levels. The data collected through the survey serves as a fundamental source for several key initiatives. The county governor receives numerous assignments through allocation letters and operational and financial instructions where figures from IS-24/8 are used as management

parameters. Figures from IS-24/8 are also utilized in the county governor's annual reporting to the Norwegian Directorate of Health. (by Google translate from Norwegian) "
The importance of the project as a knowledge base is also shown by the fact that the results are made available with interactive tool to collect information and compare municipalities, by the Resource portal (by Google translate from Norwegian) for analysis and planning for health and care services.

The report from 2021 is cited 65 times according to google scholar (28. January 2024): Ose, S. O., & Kaspersen, S. L. (2021). Kommunalt psykisk helse- og rusarbeid 2021: Årsverk, kompetanse og innhold i tjenestene. SINTEF rapport

The policy impact of the **evaluation of care pathways in specialist mental health and substance abuse treatment services** is corroborated in the following online reference (in Norwegian):

1) Interview with the Minister of health and care services (by Google translate from Norwegian) after publication of the first report.
2) Information on policy change (by Google translate from Norwegian) following the evaluation from the Directorate of health.

Google search (28. January 2024) on the title of the first report "Pakkeforløp for psykisk helse og rus-fagfolks erfaringer første året" gives **421** hits and a search on the second report "Pakkeforløp for psykisk helse og rus – brukere, pårørende og fagfolks erfaringer" gives **479** hits.

Academic impact can be documented by number of citations. The following five peer-reviewed articles are among those with the highest number of citations (google scholar 28. January 2024):

Steihaug, S., Johannessen, A. K., Ådnanes, M., Paulsen, B., & Mannion, R. (2016). Challenges in achieving collaboration in clinical practice: the case of Norwegian health care. *International journal of integrated care*, *16*(3). Citations: **95**

Kalseth, J., Lassemo, E., Wahlbeck, K., Haaramo, P., & Magnussen, J. (2016). Psychiatric readmissions and their association with environmental and health system characteristics: a systematic review of the literature. *BMC psychiatry*, *16*, 1-9. Citations: **94**

Gutiérrez-Colosía, M. R., Salvador-Carulla, L., Salinas-Pérez, J. A., García-Alonso, C. R., Cid, J., Salazzari, D., ... & REFINEMENT Group. (2019). Standard comparison of local mental health care systems in eight European countries. *Epidemiology and psychiatric sciences*, *28*(2), 210-223. Citations: **79**

Borgermans, L., Marchal, Y., Busetto, L., Kalseth, J., Kasteng, F., Suija, K., ... & Devroey, D. (2017). How to improve integrated care for people with chronic conditions: Key findings from EU FP-7 Project INTEGRATE and beyond. *International journal of integrated care*, *17*(4). Citations: **77**

Kaspersen, S. L., Pape, K., Vie, G. Å., Ose, S. O., Krokstad, S., Gunnell, D., & Bjørngaard, J. H. (2016). Health and unemployment: 14 years of follow-up on job loss in the Norwegian HUNT Study. *The European journal of public health*, *26*(2), 312-317. Citations: **73**

SINTEF_Digital – impact case #4

Institution: SINTEF
Administrative unit: SINTEF Digital
Title of case study: Cyber security in the energy sector
Period when the underpinning research was undertaken: 2003-2024
Period when staff involved in the underpinning research were employed by the submitting institution: 2003-2024
Period when the impact occurred: 2005-2024

1. Summary of the impact (indicative maximum 100 words)

Since 2002, SINTEF Digital has performed cyber security research in critical infrastructures, with the energy sector as the main vertical. Both the Oil and Gas industry (O&G) and the Power Industry (PowInd) have undergone the transition to remote control facilities by introducing standardized off-the-shelf software and hardware in their critical operations.

SINTEF Digital has continuously contributed with applied research to always ensure an acceptable level of security. Threat identification, risk analysis, guidelines, and baseline security requirements along with preparedness exercises, continuous awareness raising, and adopting these results by industry and facilitating industry arenas for collaboration and common practices are among our contributions.

2. Underpinning research (indicative maximum 500 words)

A series of related research projects in collaboration with the energy sector, partially funded by the Research Council of Norway (RCN) and the European Commission (EC), have made the research possible. The different projects have given us detailed insights into the state of the practice and what digitalization implies for security and safety in both power grids and control systems for offshore operations. We have been identifying and documenting cyber security and safety gaps in terms of the potential risks and challenges that have had to be addressed in the short and mid-long term and developed guidelines, methods, and work processes to be implemented in practice.

Even though there are indeed differences between the two sectors, they have a lot in common when it comes to technological development, organizational challenges, and threats they are facing. The scientific challenges and state-of-the-art (SotA) results are therefore in general highly applicable in both O&G and PowInd and helps move the state-of-the-practice (SotP) in both. This interplay between SotA and SotP has shown to be very fruitful. Performing research in the two sectors in parallel has strengthened our insight and results and made it possible for us to contribute even more to each of the sectors, and other sectors as well.

A few of our most relevant projects:

- DeVID – Demonstration and verification of intelligent distribution grids: We developed a method for risk evaluation related to information security/cyber security for smart meters. Demonstration activities were carried out at two demo sites in Norway (Hvaler and Steinkjer) in order to make the results more valuable to be deployed on full scale.
- FME Cineldi – A Norwegian Centre for Environment-friendly Energy Research: We performed identification and modelling of cybersecurity risks for power grid operator companies to

achieve an improved understanding of the effects of power grid digitalization on cybersecurity, as well as the impacts of cybersecurity on the reliability of supply.

- SecureGrid: We identified and documented the cybersecurity gaps in terms of the potential risks and challenges that must be addressed in short and mid-long term by the national transmission system operator in Norway and developed a cybersecurity roadmap for them.
- Stop-IT – Strategic, Tactical, Operational Protection of Water Infrastructure against Cyber-physical Threats: hands-on training, best practice guidelines, the STOP-IT platform, and specific tools such as the Strategic and Tactical Risk Assessment and Treatment Framework, a Toolbox for IT and SCADA security, a Toolbox for protection against physical threats, a Cyber Threat Sharing Service, a Public Warning Notification System and the Reasoning Engine.
- ICT security and robustness in the petroleum industry: We performed an extensive study of state-of-the-practice in the industry wrt. ICT security in control system, ICT robustness, data quality, digitalisation, IT-OT integration, and communications for emergency communication on behalf of the Norwegian Ocean Industry Authority.

Current Digital staff in bold:

- **Martin Gilje Jaatun**, senior research scientist: security in industrial control systems, cyber-physical security, IoT security, secure software engineering, security in cloud computing.
- Inger Anne Tøndel, senior research scientist, team member until 2022: digital security, privacy, secure software engineering, cyber-physical security, security in industrial control systems, requirements engineering.
- **Karin Bernsmed**, senior research scientist: cyber security, privacy (GDPR), security risk assessment, security requirements, and modelling, analysis and design of secure and robust ICT systems.
- **Per Håkon Meland**, senior research scientist: secure software engineering, threat modeling, cyber security indicators, security economics
- **Aida Omerovic**, senior research scientist/research manager (left SINTEF in 2020, returned in 2022): risk analysis, security in industrial control systems, IoT security, cyber-physical security, cyber risk management.
- Guillaume Bour, software engineer, team member 2018-2023: cyber-physical security, security in IoT, secure software engineering
- **Maria Bartnes**, research scientist, team member until 2015, and research director in Digital from 2017: incident management, preparedness exercises, risk analysis, cyber-physical security, cyber risk management.
- Atle Refsdal, senior research scientist, team member until 2018: cyber risk management, risk analysis, security in IoT, secure software engineering.
- Åsmund A. Nyre, research scientist, team member until 2014: privacy, security risk assessment, cyber risk management, secure information sharing, security in industrial control systems
- Jostein Jensen, research scientist, team member until 2014: identity management, cyber risk management, secure software engineering, security in industrial control systems

3. References to the research (indicative maximum of six references)

Tøndel, I. A., Jaatun, M. G., Line, M. B.: Threat modeling of AMI, 7th International Workshop on Critical Information Infrastructures Security (CRITIS), Lillehammer, Norway, September 17-18, 2012. Springer 2013 ISBN 978-3-642-41484-8. p. 264-275. https://link.springer.com/chapter/10.1007/978-3-642-41485-5_23

Bartnes, M., **Moe, N. B**., Heegaard, P. E.: The future of information security incident management training: A case study of electrical power companies, Computers & Security vol. 61, ISSN 0167-4048, p. 32-45, August 2016. https://www.sciencedirect.com/science/article/pii/S0167404816300530

Martin Gilje Jaatun: "Security in Critical Information Infrastructures", Doctoral thesis, UiS 2015. https://uis.brage.unit.no/uis-xmlui/handle/11250/293101

Aida Omerovic, Hanne Vefsnmo, Oddbjørn Gjerde, Siri T. Ravndal and Are Kvinnesland: An Industrial Trial of an Approach to Idenfication and Modelling of Cybersecurity Risks in the Context of Digital Secondary Substations, In Proceedings from 14th Conference on Risks and Security of Internet and Systems (CRiSIS) 2019, ISBN 978-3-030-41568-6 in Springer Lecture Notes (LNCS) ISSN 0302-9743, pp 17-33, 2020. https://doi.org/10.1007/978-3-030-41568-6_2

Tor Onshus, **Lars Bodsberg, Stein Hauge, Martin G. Jaatun**, Mary-Ann Lundteigen, **Thor Myklebust**, et al.: Security and Independence of Process Safety and Control Systems in the Petroleum Industry, Journal of Cybersecurity and Privacy (JCP), vol 2, pp 20-41, e-ISSN 2624-800X. https://doi.org/10.3390/jcp2010003

4. Details of the impact (indicative maximum 750 words)

The fundament for this research was made by the national funded competence centre “Centre for Information Security” (SIS), with a trial period from 2002 to 2005 at SINTEF Digital. It was later permanently established as the Norwegian Centre for Information Security (NorSIS). Based on the acquired knowledge of threats, challenges, and current knowledge about information security in Norwegian companies, we initiated the research project Incident Response Management (IRMA), to understand and improve how cyber security incidents in the oil and gas industry, and specifically to their industrial control systems, were responded to and dealt with.

Cyber security for industrial control systems was an immature field of both research and practice, we saw the need for research to develop new knowledge, new methods, and new work processes, in close collaboration with industry to help them succeed with implementing new technologies to achieve goals of efficient and smart management of critical processes.

Our research has been carried out in different kinds of projects with many collaborating institutions. The PhD degrees achieved have been granted by The Norwegian University of Science and Technology (NTNU) and University of Stavanger (UiS).

The PowInd research projects have been both national and international, and SINTEF Energy has been our most important partner as they have the domain expertise and complementary scientific knowledge to our cyber security expertise. They provide us with the Smart Grid Lab and well-established network of power grid operators and suppliers in Norway. SINTEF Community has been an important partner in our international research projects within the domain of water infrastructure, while O&G industry projects have mainly been national direct industry projects. The Norwegian Ocean Industry Authority (aka previously as PSA, but Havtil for short as of 1. January

2024) and the Norwegian Energy Regulatory Authority (NVE) have been our two most important collaborators and customers in making research results available for the industries and improving state-of-the-practice.

We have contributed directly to several guidelines and best practices for the oil and gas industry, starting with an information security baseline for the Norwegian O&G (materialized in OLF-104), which was co-created with both operator companies and suppliers.

Further, we have established the CDS-forum – Industry Forum for Cybersecurity of Industrial Automation and Control Systems, with regular meetings for O&G operators, suppliers, authorities, and academia to discuss challenges and opportunities within cyber security for industrial control systems.

Similar for the PowInd, we have developed guidelines for cyber security risk assessments and requirements for smart meters in direct collaboration with the authorities, and these guidelines have been treated as requirements for the power industry. The first edition of the security requirements for smart meters were published in 2012, then we evaluated them in 2017 and published a second edition in 2022 (both in Norwegian) – all these were deliverables ordered from the authorities, and our research forms the fundament for the content in all these guidelines.

Further, in 2014 we published a report on how to perform risk analysis of smart meters (in Norwegian). In 2023 we performed a prestudy on behalf of the NVE on how to make appropriate demands for cyber security in procurement processes (in Norwegian). All these deliverables and our close collaboration with companies in the PowInd have contributed to defining a baseline level of information security for the industry in Norway and an improvement of practice.

5. Sources to corroborate the impact (indicative maximum of ten references)

- 2017: Evaluation of the guideline for cyber security in smart metering infrastructure from 2012. SINTEF researchers created the guideline in 2012 and this evaluation (in Norwegian only): https://sintef.brage.unit.no/sintef-xmlui/handle/11250/2448304
- 2022: Guideline for cyber security in smart metering infrastructure (in Norwegian), published by the Norwegian Energy Regulatory Authority, written by Hanne Sæle, Maren Istad (both from SINTEF Energy) and **Martin Gilje Jaatun**. https://publikasjoner.nve.no/rme_veileder/2022/rme_veileder2022_01.pdf
- 2023: **Knut Øien**, **Lars Flå**, **Stein Hauge**, **Martin G. Jaatun**: *A Barrier-based Approach to Cyber Security in Critical Infrastructures*, Feature article in the Bridge, the Magazine of IEEE-Eta Kappa Nu, Issue 2 Vol 119, Cybersecurity for Critical Infrastructure, 2023.
- The Infosec blog: https://infosec.sintef.no/blogg/ (most posts are in Norwegian). Blog established in 2011 and has been an important communication channel from our cyber security activity to the public. Posts have covered recent research results, reports/white papers to the industry, master theses, meet-ups, and other information relevant to a broader audience.

All guidelines from the Norwegian Energy Regulatory Authority to the Norwegian grid operators, power producers, and suppliers are written in Norwegian only. In the oil and gas industry and for all activity on the Norwegian Continental Shelf, the main language is English.

SINTEF AS, SINTEF Digital, Impact Case number 5

Institution: SINTEF AS
Administrative unit: SINTEF Digital
Title of case study: Decision support tools for aviation safety
Period when the underpinning research was undertaken: From the 90-ties until now
Period when staff involved in the underpinning research were employed by the submitting institution: From the 90ties until now
Period when the impact occurred: 2009–2024, continuous period, dates difficult to pinpoint

1. Summary of the impact

SINTEF Digital has been involved in mathematical modeling since the beginning (1950) and delivered more and more impact in the aviation domain. Two of the main areas of application are the development of a local turbulence forecaster and aircraft noise calculations.

In Norway, we have many rather small airports with short runways spread around in the districts, especially on the west coast and the northern part of the country. The airports are very important to the local businesses and the population, even though the number of passengers is relatively small. In many places, aviation is seen as the common public transport and the only alternative for traveling far in a reasonable time, even if you are only going to a hospital for a check-up or to visit the dentist. Due to topography and climate, the operations may be challenging, and local turbulence close to airports has caused fatal aircraft accidents. The research and development SINTEF Digital has conducted together with the national airport owner Avinor and Meteorological Institute (MI) has resulted in an implemented system where the pilots get the forecasted local turbulence around airports when they plan their flight – not only the commonly available forecast of the wind.

Aircraft noise has become more and more important as a negative emission from aviation, especially related to take-off and landings at airports (small or big) in populated areas. SINTEF Digital has, together with Avinor and the Norwegian Defence Estates Agency (NDEA - Forsvarsbygg) developed, maintained, and implemented models for aircraft noise measurements. The work has been in cooperation with the Federal Aviation Authorities (FAA) and EUROCONTROL and has been digitalized so that customers may get noise reports online.

2. Underpinning research

The interest in terrain-induced turbulence started already in 1990 with the Værøy Accident (see section 4). This sparked the original development of terrain-induced turbulence modeling [6] and what would become the SIMRA system for local wind predictions with a specific focus on terrain-induced effects and local topography. Initial implementations only allowed for hindcast and a posteriori analysis. The code was subsequently improved and parallelized in the period 1999-2004 and now allowed for forecast and real-time predictions. The work was a collaboration with the MI. SIMRA was deployed in operational use from 2009 **as the world's first and only real-time turbulence alert system**.

The next generation SIMRA introduced sophisticated meshing techniques which allowed the system to be deployed at new airports in a fast pace, and it currently serves around 20 airports. In later years the system has seen use in the AI revolution where it has been used to extensively train surrogate models and augmented by hybrid analytics such as the work

[2] to enable super-resolution reconstruction of wind fields using Generative Adviserial Networks (GANs). SIMRA provides wind- and turbulence predictions for any mountainous terrain and has seen applications outside of aviation as well, such as analysing the suitability of new bridges [1].

SINTEF Digital's aircraft noise research began as a response to governmental needs for noise assessment and initiated the development of the Norwegian calculation model called NORTIM. The model took into consideration the impact of topography on sound propagation. The development of NORTIM was a collaborative effort involving SINTEF, with financial support by Avinor and NDEA.

Over the years, research has led to validation and calibration of the NORTIM calculation model. NORTIM is now considered highly reliable in reflecting real-world situations. The research has positioned NORTIM at the front of aircraft noise modelling, particularly in methodology and prediction of special cases. This includes noise propagation near water, terrain blockage, shielding effects, effective data processing, and automatization.

In 2019, the work on SICALC (SINTEF Noise Calculator) started based on the NORTIM engine, which is a new online noise calculation tool and service. The concept has a strategic goal that aims to make outdoor noise calculations accessible to everyone, minimize calculation time, and deliver results with high quality. This is in contrast to the current practice, where such calculations require costly aircraft noise experts.

The goal of faster calculations has included research on parallelization on multiple processors and on GPUs, which included the topic of how to keep the expert domains of acoustics and parallelization separate. Faster calculation has also been achieved by research into storage and reusability of results from heavy calculations.

In 2023, a prototype of the software was launched. The software allows users to make calculations in a web-based interface, and much faster than previous tools. The benefit can be from halving of today’s time usage or more, depending on the complexity of the task and the calculation one wishes to perform.

Key researchers involved in the development of SIMRA:

- Torbjørn Utnes: scientist and author of the first version of the SIMRA code together with Eidsvik. Parallelization of the code. Retired
- Karl Johan Eidsvik: scientist and author of the first version of SIMRA. Calibration and verification with Norwegian Met Centre. Retired.
- Adil Rasheed: senior scientist, joined in 2009, extended support for unstructured mesh. Developed high quality mesh tools. AI coupling of SIMRA using hybrid analytics and modelling.
- Mandar Tabib: senior scientist, joined in 2011, primary investigator for many airport-specific case studies such as Lofoten and new building requests. Multiscale coupling of SIMRA with the open source CFD solver OpenFOAM.
- Arne Morten Kvarving: scientist and current code maintainer, joined in 2011. Manages build systems and continuous integration. Modernized the code substantially.

Key researchers involved in the development of NORTIM/SICALC:

- Herold Olsen: senior scientist. Main developer of NORTIM prior to 2001. Work includes software and model development, reusability of results, and international research on aircraft noise.

- Idar L. N. Granøien: senior scientist. Involved in the development of the first version of NORTIM, and international research on aircraft noise. Retired.
- Rolf Tore Randeberg: research scientist. Main developer since 2001. Work includes software and model development, reusability of results, and GPU/CPU parallelization of noise calculation algorithms.
- Leo Heggem Hauge: Master of Science. Work includes development of SICALCs user interface, and international research on aircraft noise. Joined in 2021.
- Karen Brastad Evensen: research scientist. Work includes reusability of results, and validation of the SICALC calculation model. Joined in 2019.
- Kjetil Olsen Lye: research scientist. Work includes GPU/CPU parallelization of noise calculation algorithms. Joined in 2020.

3. References to the research

[1] Z. Midjiyawa, **J. V. Venås**, **T. Kvamsdal**, **A. M. Kvarving**, K. H. Midtbø, and **A. Rasheed**, 'Nested computational fluid dynamic modeling of mean turbulent quantities estimation in complex topography using AROME-SIMRA', *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 240, p. 105497, Sep. 2023, doi: 10.1016/j.jweia.2023.105497.

[2] D. T. Tran, H. Robinson, **A. Rasheed**, O. San, **M. Tabib**, and **T. Kvamsdal**, 'GANs enabled super-resolution reconstruction of wind field', presented at the Journal of Physics: Conference Series, IOP Publishing, 2020, p. 012029. doi: 10.1088/1742-6596/1669/1/012029.

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[4] **T. Utnes**, 'Modelling of Stratified Geophysical Flows over Variable Topography', in *Geometric Modelling, Numerical Simulation, and Optimization*, G. Hasle, K.-A. Lie, and E. Quak, Eds., Berlin, Heidelberg: Springer Berlin Heidelberg, 2007, pp. 361–390. doi: 10.1007/978-3-540-68783-2_11.

[5] **I. L. N. Granøien**, **R. T. Randeberg**, and **H. Olsen**, 'Corrective measures for the aircraft noise models NORTIM and GMTIM. 1) Development of new algorithms for ground attenuation and engine installation effects 2) New noise data for two aircraft families', 2002. Accessed: Jan. 19, 2024. Available: https://urn.nb.no/URN:NBN:no-nb_digibok_2016082608023

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[7] **I. Granøien**, **K. H. Liasjø**, **H. Olsen** (1995) 'Topography influence on aircraft noise propagation, as implemented in the Norwegian prediction model, NORTIM' SINTEF report STF40 A95038. Available: Topography influence on aircraft noise propagation, as implemented in the Norwegian prediction model, NORTIM. (researchgate.net)

4. Details of the impact

The interest in terrain-induced turbulence started already in 1990 with the Værøy Accident in which a small aircraft crashed shortly after take-off due to a sudden change of wind direction resulting in five casualties. This sparked the development of the SIMRA code for local wind predictions with specific focus on terrain-induced effects and local topography. In 2005, there was another accident in Hammerfest in which the aircraft crash investigation called for several improvements, among others better local wind predictions: SIMRA was deployed in operational use in 2009 improving the safety of aviation. Norway has the additional challenge of short runways on smaller airports and highly mountainous terrain. The system was a success, and in the period following 2009-2016 it was embraced by the

Norwegian Aviation industry and upscaled to include more and more Norwegian airports and at present serves around 20 airports. During this period several verification projects were conducted to assert and improve the accuracy of the system in collaboration with the MI. The system has also been used to assert the feasibility of new airport locations, such as the newly planned airport in Lofoten in 2016 where SIMRA was used to analyze several locations (in Norwegian) and ultimately resulting in Leknes to be the new airport location. Lofoten is not only of national interest, but the area is well known abroad and attracts a lot of tourists. Locating a modern and effective new airport here, need to take care of environmental issues, transfer to and from the airport, local settlements and businesses, and of course wind patterns and local turbulence. SINTEF Digital contributed to analyses of 4 potential locations for the new Lofoten airport. In 2021-2023 it was also used in the national project ferry-free E39 to assess wind- and turbulence conditions for new bridges to be built across fjords in mountainous terrains. The societal impact of the system is impressive, and since the system has been operational no accidents have been reported in which wind and/or turbulence was the primary culprit.

SIMRA has played a crucial role in enhancing aviation safety by influenced by the surrounding terrain. Unlike traditional turbulence detection systems that rely solely on historical or forecasted data, SIMRA systems offer a more immediate and accurate understanding of turbulence patterns, contributing to a proactive approach in risk management. This section explores how the real-time assessment of terrain-induced turbulence significantly lowers the risk of accidents in aviation.

SIMRA systems integrate advanced predictive capabilities that enable them to anticipate and analyse turbulence patterns based on the specific characteristics of the surrounding terrain. By continuously updating turbulence predictions in real time, these systems empower pilots to take proactive measures to avoid potential hazards, reducing the likelihood of encountering severe turbulence and enhancing overall flight safety. Not only the flight safety improved, but by using SIMRA as a planning tool for flights where the pilot expects turbulence at and around an airport the pilot can plan the flight trajectory accordingly, to avoid turbulence and the passengers get a smoother flight.

The system has also been used in a series of verification projects for newly proposed buildings and hangars in airport vicinities: including, but not limited to Bodø, Sola, Kjevik, Kristiansund, Alta. This is to avoid adverse wind effects on near-runway flight conditions. For instance, was the final aerodynamic design of the Skanska building near Sola airport is a result of this work.

Research on aircraft noise has provided a crucial foundation for work related to noise annoyance, determined calculation methodologies, and identified essential parameters to consider. NORTIM has for many years been the official method for aircraft noise calculation in Norway, meeting international standards such as ECAC Doc 29. It has played a role in significant decisions and legal proceedings in Norway, including the Gardermoen trials, the military airbase in Ørland, the placement of the proposed 3rd runway at Oslo Airport, and the establishment of heliports at hospitals among others. In tandem with evolving regulatory requirements and calculation modules, SINTEF has continually advanced NORTIM in close collaboration with Avinor and NDEA.

Various stakeholders benefit from the results of efficient aircraft noise calculations. Airport owners, like Avinor and NDEA, conduct regular noise level assessments at their airports. These assessments are reported to authorities in Norway and EU. Avinor manages a total of 45 airports, while NDEA manages four military airbases. In addition, there are heliports for

most hospitals, as well as local private airports and helicopter landing sites which also require noise calculations. Noise calculations are used to determine the total noise emission from the airport, providing an overview of how many buildings and people are exposed to noise at various levels. These results are then evaluated against national regulations. The results are important when identifying the correct measures for buildings or when one is planning arrival and departure routes to minimize the noise annoyance for neighboring houses and people. There are several factors to consider while planning standard arrival and departure routes to and from airport or heliport, such as aircraft characteristics and separation between the different routes. With the NORTIM tool the airport operator is able to see the different noise patterns for the different alternatives already during the design phase. SINTEF Digital has also offered the software to a Norwegian aviation simulator provider (Edda Systems), so that they may include the noise feature in their eCoach Airspace Planner product (last bullet in the brochure).

Furthermore, acoustics consultants rely on results of noise assessments for building applications submitted to municipalities, development plans for areas, and evaluations of building-related measures.

Research from 2019 to 2023 has focused on achieving faster calculations through parallelization, smart algorithm usage, and user interface improvements. In 2023, a prototype of the software was launched, where users such as acoustical consultants and airport owners can perform fast noise calculations by themselves in an online tool. This is a huge improvement in time and cost compared to the earlier practice where such calculations required experts in aircraft noise at SINTEF.

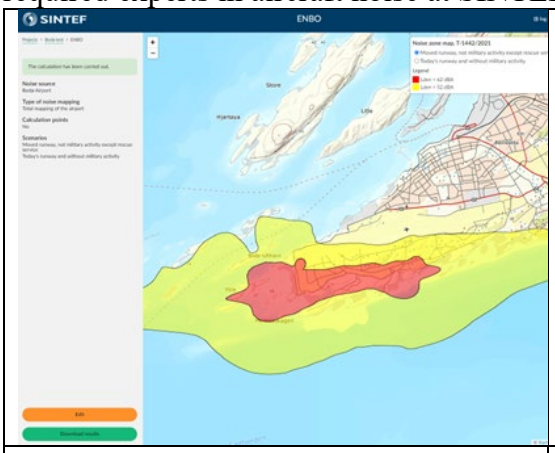


Figure 1a: Noise map of Bodø airport showing noise level in form of yellow and red zones.

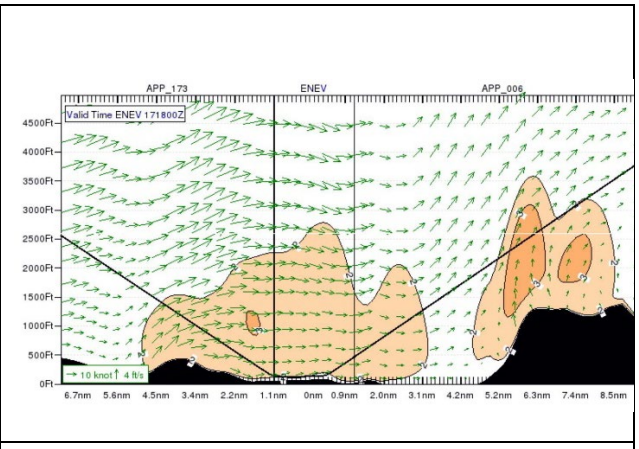


Figure 1b: Vertical turbulence map of Evenes airport showing the flight trajectory as a solid black line, calm air as white, turbulent air orange and mountains black.

5. Sources to corroborate the impact

- **SICALC:** https://www.sintef.no/en/projects/2020/sicalc/
- **Avinor noise maps:** Noise Restriction Zone Map – Avinor
- **Avinor interactive noise map:**
- https://api.avinor.no/karttjenester/flystoy/lufthavn.html?iata=OSL
- **List of Norwegian Aviation accidents** (no turbulence related after SIMRA installation)**:** https://en.wikipedia.org/wiki/List_of_aviation_accidents_and_incidents_in_Norway
- **Realtime Turbulence map** (click an airport followed by "Turbulence Maps")**,** https://www.ippc.no/ippc/index.jsp

SINTEF Industry Case Number 1

Institution: SINTEF AS
Administrative unit: SINTEF Industry
Title of case study: Solvit program for CCS
Period when the underpinning research was undertaken: 2008 - 2023
Period when staff involved in the underpinning research were employed by the submitting institution: from before 2008 - 2023
Period when the impact occurred: 2008 - 2023

1. Summary of the impact

The Solvit project involving Aker Solutions, SINTEF and NTNU was one of the largest research projects at SINTEF. It has had a major impact in the field of Carbon Capture technology, positioning Aker as one of the worlds leading technology providers. It was also the basis for the construction of SINTEFs CO2Lab pilot, which has been used in benchmarking and development of technologies for a wide range of international companies. The project also established a close relationship between SINTEF, NTNU within CCS, with the education of a large number of students that have been recruited both by Industry and SINTEF.

Underpinning research

Post combustion Capture of CO2 emissions from industrial and refinery processes has been of increasing focus and is now one of the key approaches for the mitigation of climate change. Solvent based capture processes are one of the approaches that has been of most promise for implementation at last scale worldwide. International development activities have been focusing on reducing the overall costs for implementation – one of the main drivers for adoption of the technology. Key aspects related to implementation have included the properties and performance of the solvent, the long-term stability, potential emissions of degradation products and their environmental impact as well as benchmarking of these performances under realistic conditions for evaluation of their industrial potential.

A key component of this type of technology is the selection, testing, validation and benchmarking of the solvent. To obtain valid results at an international level and for use in industrial application, this involves the application of a wide range of experimental and theoretical approaches in order to obtain accurate and realistic results. This includes the fundamental understaning of the chemistry of the solvent technology, measurement of fundamental chemical and thermodynamic properties of the processes, development of robust models of the solvent systems and overall process, experimental evaluation of long term degradation processes, advanced analytics for measurement of the complex degradation processes as well as experimental systems for measuring the performance in the capture process under conditions that can be transferred to industrial scale.

Names of the key researchers and what positions they held at the administrative unit at the time of the research:

- Ole Wærnes – Research Director
- A Grimstvedt - Scientist
- K Zahlsen – Research Manager
- SJ Vevelstad - Scientist
- T. Mejdell – Senior Scientist
- KA. Hoff – Senior Scientist
- FA Tobiesen – Scientist
- Eirik Falck da Silva, Senior Scientist
- Olav Juliussen, Senior Scientist
- A Chikukwa - Scientist

3. References to the research

- A Grimstvedt, K Zahlsen, SJ Vevelstad, K Vernstad, T Holten, A Brunsvik. «Exploration of degradation chemistry by advanced analytical methodology". Energy Procedia 00 (2017) 000–000 (in press)
- Gorset, JN Knudsen, OM Bade, I Askestad. «Results from testing of Aker Solutions advanced amine solvents at CO2 Technology Centre Mongstad». Energy Procedia (2014), 63, 6267-6280.
- JN Knudsen, OM Bade, I Askestad, T. Mejdell. «Pilot Plant Demonstration of CO2 Capture from Cement Plant with Advanced Amine Technology". Energy Procedia (2014) 63, 6464-6475.
- JN Knudsen, OM Bade, M Anheden, R Bjorklund, O Gorset, S Woodhouse: "Novel Concept for Emission Control in Post Combustion Capture". Energy Procedia (2013), 37, 1804–1813.
- FA Tobiesen, M Hillestad, H Kvamsdal, A Chikukwa, "A general column model in CO2SIM for transient modelling of CO2 absorption processes", Energy Procedia 23 (2012) 129 – 139, doi: 10.1016/j.egypro.2012.06.071

- 4. Details of the impact

- SOLVit was an eight year research programme, spanning the period of 2008 – 2015 with a large budget of 37 million Euro. The focus of the research was on developing energy efficient and environmentally friendly post combustion carbon capture systems for large-scale industrial CO2 emissions. The overall aim of the SOLVit programme was to reduce the costs of CO2 post combustion capture through the development of more energy efficient solvent systems.

- The project was established between Aker Solutions, SINTEF and NTNU, with the work within the fields of solvent development, process optimisation and operational understanding through pilot plant testing.
- The research covered all levels of technology development from fundamental Studies, modelling through to Technology Development and Pilot Plant Testing and Demonstration.
- As an output from the project, several new solvents were developed, improving the energy consumption relative to reference MEA along with significantly improved degradation and environmental performances.
- In terms of impact:
- The improvement of the maturity of Aker Solutions' Advanced Carbon CaptureTM process significantly. This technology development is the basis for technology of Aker Carbon Capture, which is amongst the leading providers of turnkey Carbon Capture Solutions, selected for the world's first full scale CCS facility for cement production. (https://www.brevikccs.com/en)
- The establishment of SINTEF's CO2Lab full height pilot unit for comprehensive testing and benchmarking of amine-based carbon capture processes (https://www.sintef.no/en/all-laboratories/co2-laboratory-tiller/). The pilot has been selected for benchmarking and validation of technologies for a range of international companies and recently celebrated 100.000 hours of operation.
- The development of CO2SIM, a full flow sheet in-house process simulator "CO2SIM" for solvent based CO2 capture processes. CO2SIM has been used to develop solvent models for all the solvent systems tested in pilot plants used to validate data from the pilot plant campaigns. It was recently enhanced to function as a Digital Twin of the CO2Lab pilot.
- Fundamental understanding of the emissions from the solvent-based capture process, in particular degradation chemistry, environmental impact and development of chemical analysis for solvents and their degradation products.
- The expertise and knowledge has positioned SINTEF as one of the internationally leading research groups, taking a leading role in a number of European research initiatives together with major industrial partners aiming to implement CCS.

5. Sources to corroborate the impact

- Jacob N. Knudsen, Ole Wærnes, Hallvard F. Svendsen, Oscar Graff, "Highlights and main findings from the 8 year SOLVit R&D programme – Bringing solvents and technology from boratory to industry", Energy Procedia (2017) 114 5701 – 5710.doi: 10.1016/j.egypro.2017.03.1709

- Rabindran, Aravind and Gupta, Vijay and Tanthana, Jak and Mobley, Paul and Lail, Marty and Tobiesen, Andrew and Mejdell, Thor and Hjarbo, Kai and Grimstvedt, Andreas and Wiig, Merete and Hohvdal, Lars, Development of a rate-based model for CO2 capture using a non-aqueous hydrophobic solvent (March 25, 2021). Proceedings of the 15th Greenhouse Gas Control Technologies Conference 15-18 March 2021, Available at SSRN: https://ssrn.com/abstract=3812568 or http://dx.doi.org/10.2139/ssrn.3812568

- https://www.drax.com/press_release/5m-boost-scale-ground-breaking-carbon-capture-pilot-drax-uks-largest-power-station/

-
- https://climit.no/en/project/piloting-so2-scrubbing-of-flue-gases-prior-to-post-combustion-co2-capture-so2solve/

SINTEF Industry Case Number 2

Institution: SINTEF AS
Administrative unit: SINTEF Industry
Title of case study: Multiphase research
Period when the underpinning research was undertaken: 2011 - 2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2011 - 2022
Period when the impact occurred: 2011 - 2022

1. Summary of the impact

Research within the field of Multiphase flow has been an important enabler for Norway's Oil and Gas exploration, with the Multiphase Flow Lab hosted by SINTEF being identified as one of Norway's most important innovations. The fundamental understanding of measuring and modelling multiphase mixtures from ocean reservoirs is having major impact in new areas – in particular related to research contributing to reducing emissions, including transport and storage of CO2. One major impact is SINTEF and Kongsberg Digital's co-development of the Ledaflow simulator which is pioneering applications within CO2 transport and storage.

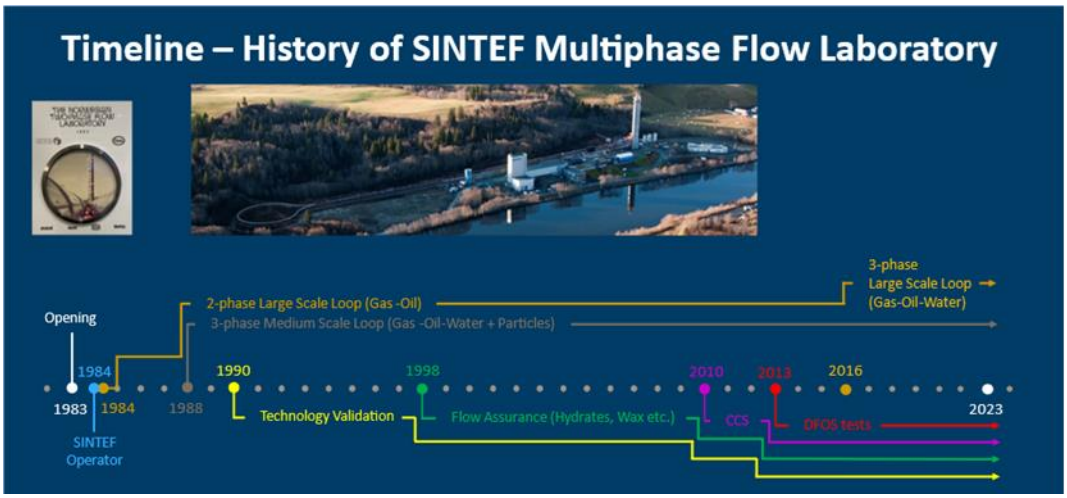
2. Underpinning research

Multiphase transport is the key factor that has enabled fully integrated production facilities to be installed on the seabed. It has allowed oil and gas to be recovered offshore without the high levels of energy consumption and greenhouse gas emissions that the construction of new production platforms entails.

The results of the pioneering work carried out by SINTEF and IFE in the 1980s remain the foundation of the computational models that are used to design and operate multiphase installations down to the seabed.

In collaboration with SINTEF Digital, these advanced models which which are much used worldwide have been implemented in the multiphase simulator called LedaFlow. The development of this simulator was part of a joint effort between SINTEF and the oil companies TOTAL and ConocoPhillips.

Underpinning the development of advanced models, has been the experimental work carried out within the Multiphase Flow Laboratory, one of the world's largest multiphase test facilities, which has been operated under realistic industrial scales. In addition to the underpinning research within the physical infrastructure, the Multiphase laboratory has also one of the largest, high-quality multiphase flow databases at industrial scale in the world.



Andrea Shmueli Alvarado	Research Manager	Nov-14	to date
Tor Erling Unander	Senior Researcher	Oct. 2002	to date
Martin Fossen	Senior Researcher	2007	to date
Jørn Kjølaas	Senior Researcher	2001	to date
Heiner Schümann	Senior Researcher	Sep-15	to date
Galina Simonsen	Senior Researcher	June 2020	to date
Ivar E. Smith	Researcher	Sep-07	to date
Loïc Duffo	Researcher	Nov-22	to date
Kristine Midtbø	Researcher	Sep-23	to date
Diana Gonzalez	Researcher	Sep-22	to date
Grethe Tangen	Senior Researcher	2014	to date
Paul Roger Leinan	Researcher	2014	to date
Halvard Thon	Instituttstipendiat & researcher	Aug-21	to date
Steffan Krimmel	Guest researcher	Mar-21	Dec 2021
Espen Krogh	Researcher	?	2016
Marita Wolden	Researcher	?	June 2022
Christian Brekken	Senior project manager	?	2022
John Harald Kaspersen	Research director	Dec 2006	Apr-17
Roar Larsen	Senior researcher		2016
Bjørnar Lund	Senior researcher		2016
Roel Belt	Senior Researcher	Mar-12	Jan-14

3. References to the research

1. Thomas John Danielson; Krishan M. Bansal; Biljana Djoric; Dominique Larrey; Stein Tore Johansen; Angela De Leebeeck; Jorn Kjolaas, "Simulation of Slug Flow in Oil and Gas PIpelines Using a New Transient Simulator", Offshore Technology Conference, Houston, Texas, USA, April 2012.
2. J. Kjolaas; H. Holm, "Improvement of LedaFlow for low liquid loading conditions", 10th North American Conference on Multiphase Technology, Banff, Canada, June 2016.
3. Kjølaas J., Unander T.E., Wolden M., Schümann H., Leinan P.R., Smith I.E., Shmueli A. *"Large scale experiments on slug length evolution in long pipes" (2020) SPE Production and Operations, 35 (4), pp. 895 – 909, DOI: 10.2118/203827-PA*
4. J. Kjølaas; A. Shmueli; A. Morin; R. Belt, "Improvement of LedaFlow for churn flow in vertical pipes", 18th International Conference on Multiphase Production Technology, Cannes, France, June 2017.
5. J. Kjølaas; I. E. Smith; C. Brekken, "Pseudo slug flow in viscous oil systems - experiments and modelling with LedaFlow", 11th North American Conference on Multiphase Production Technology, Banff, Canada, June 2018.
6. H. Schümann, M. Fossen, "Oil-water dispersion formation, development and stability studied in a wheel-shaped flow loop" (2018) Journal of Petroleum Science and Engineering, pp. 567 - 576, DOI: 10.1016/j.petrol.2017.10.066

7. Kjølaas J., Unander T.E., Wolden M., Johansson P.S., Holm H. "*Experiments for low liquid loading with liquid holdup discontinuities in two- and three-phase flows" (2015) BHR Group - 17th International Conference on Multiphase Technology 2015, pp. 327 - 342,*
8.

4. Details of the impact

Developing models for safely transporting and injecting CO2, both with and without impurities is important in realising the full value CCS value. In particular, impacting the design margins and investment costs from the safe transport and injection of CO2. One example project in this field is the CO2Flow project led by Kongsberg Digital, which is part of advancing the potential of the multiphase simulator LedaFlow (https://ledaflow.com/). The goal has been to produce robust and accurate simulations that enable the safe and cost-efficient transport and injection of CO2. Through the success of this and related projects, the results are commercialised by Kongsberg Digital for use by industrial partners, contributing to accelerating the global deployment of carbon capture and storage (CCS) technology.

Another example impact is from 2023 from the collaboration with OMV on their Berling field, looking to make the development as profitable with lowest climate impact at production. The project addressed the major challenges of gas hydrate production at the sea bed stopping production. SINTEF's multiphase flow modelling expertise was the basis of research that has shown that theoretical models were too conservative and that it was not necessary to install heating cables out to the field. Thus, SINTEF's studies confirmed that OMV could avoid the «hydrate zone» resulting in financial savings, lower energy consumption in addition to lower emissions from emitting significantly less CO2 than a pipeline that needs heating cables.

Another example is related to the developments of future offshore oil and gas fields, which are most likely to be "satellite developments" that are less expensive and emit less greenhouse gases than other fields, because they avoid the use of new production platforms. Based on the multiphase flow expertise, a simulation model was developed to meet one of the biggest challenges created by this form of pipeline transport – the formation of slugs. These limit the distance at which a satellite field can be developed from its host facility and require that major safety margins are built into the design of multiphase facilities. Slugging causes massive fluctuations in flow rates and results in vibrations along the pipelines, reducing pipeline lifetime and potential of flooding the separators in the reception facility.

The development of a slugging simulation tool predicts both the frequency and length of the liquid plugs that form in the pipelines, having an accuracy that allows the possibility of increasing the multiphase pipeline transport distances. This new knowledge about slugging also creates opportunities for more optimal design of reception facilities installed on host platforms, with the potential of avoiding oversizing and reducing energy costs. The new computational modelling tool - "Slug Capturing 2" - is incorporated into the LedaFlow package, enabling the design of longer pipelines that will allow many more fields to be developed as satellites.

5. Sources to corroborate the impact

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- https://www.sintef.no/en/latest-news/2023/sintef-to-use-its-world-class-co2-flow-facility-and-multiphase-modelling-expertise-to-develop-a-unique-simulator-for-co2-transport-and-injection/
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- https://search.patentstyret.no/Patent/20121114/?searchId=1740867&caseIndex=0
- https://search.patentstyret.no/Patent/20121255/?searchId=1741070&caseIndex=0
- https://patents.justia.com/patent/11709980

Institution: SINTEF Industry
Administrative unit: Department Applied Geoscience
Title of case study: Shale as a barrier for plugging oil wells
Period when the underpinning research was undertaken: 2013-2021
Period when staff involved in the underpinning research were employed by the submitting institution: Key staff has worked in SINTEF from 20-39 years, 1985- today
Period when the impact occurred: 2015-2022

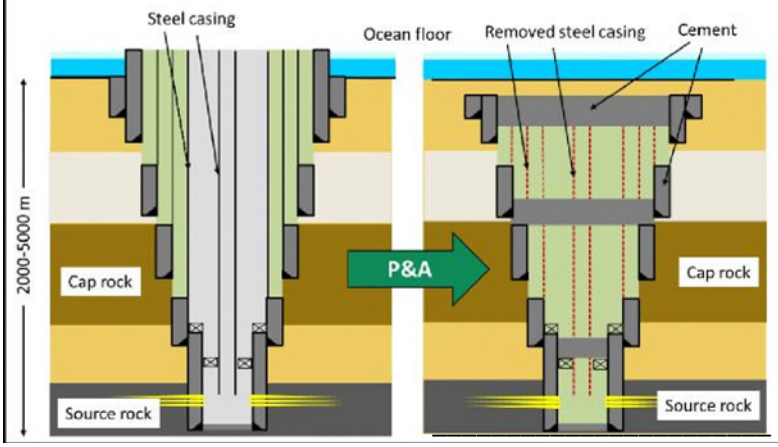
NB! Statements from the industry regarding impact in section 4 have been deleted as requested. This information is only for RCN and the reviewers NB!

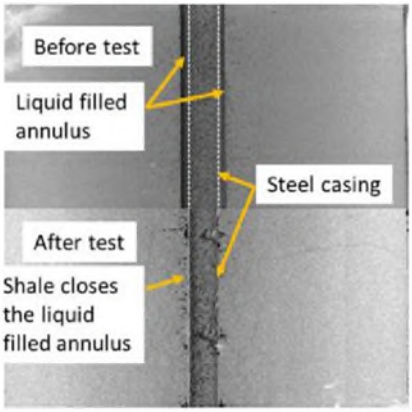
1. Summary of the impact (indicative maximum 100 words)

An estimated 7000 oil wells need to be plugged and abandoned (P&A) on the Norwegian Continental Shelf (NCS) within 2050. The petroleum industry estimates the total plugging costs to be as high as 1 000 billion Norwegian kroner (NOK). Because of the current tax regulations in Norway, the state (you and me) indirectly pays 78% of the costs. Finding new ways of plugging these oil wells that is safe but more cost efficient is therefore vital. NCS is a mature oil province and is as such in the position to develop new methods and technology to reduce the huge cost of P&A. Knowing that total amount of wells to be plugged in the world is more than 4 million and that we are drilling approximately 500 000 new wells for the next 3-5 years the international market is a huge possibility for export of new technology for P&A. The whole value chain from technology suppliers, service companies and operating companies can benefit from this concept in addition to the societal effects. The shale as a barrier concept for P&A has a large potential to cut cost and remain safe at the same time. A potential cost cut upwards to 50% of can be possible. Giving an estimate of approximately 500 billion NOK cost reduction for the NCS alone when all oil wells are plugged. Enabling more cost-effective solutions for plugging oil and gas wells can also have an impact for CO2 wells for O2 storage. So, there is an additional potential impact of this concept for future CO2 wells. Here, we do not have estimates of potential cost reduction impact. As stated from 3 of our industry partners, the scientific basis from delivered from SINTEF has already contributed to performing P&A operations with lower safety risks, substantial cost reductions as well as lower emissions.

Underpinning research

For millions of years, oil and gas has been "wrapped up" under kilometres of impermeable shale (cap rock). The oil and gas industry has inflicted this layer of shales with thousands of "wounds" by drilling wells down to where the oil and gas reserves are (source rock). When oil fields are decommissioned all oil wells needs to be plugged to ensure no leakages for eternity. To plug an old oil well is almost as comprehensive as drilling a new one. When establishing an oil well you drill first with a large drill, and you insert a steel casing and fill up with cement on parts of the outside of the casing (between the casing and the cap rock). Then you drill with a smaller drill and do the same procedure until you





reach the source rock where the oil or gas is. The total length of the well can be several thousand meters (se figure). When you plug an old well you must use a rig designed to remove all of the steel casings from the well and then insert three large cement plugs into the well to make it completely sealed for eternity, which is the requirement. Removing the steel casing and inserting cement plugs requires a rig to operate for 20-60 days which is a costly operation. Finding a solution where it is not necessary to use a rig would potentially cut costs substantially. The cap rock on the NCS is typically a shale. In the section where we have a steel casing, it is surrounded by a liquid filled annulus and then shale. Test has been performed at SINTEF showing that this liquid filled annulus will be closed by the shale, creating an impermeable barrier. An impermeable barrier outside the casing makes it now easy to fill the steel casing with cement to permanently seal the well without having to remove the steel casing. The "shale as a barrier concept" has not only the ability to **cut costs** which is beneficial for society and the industry but also lower the **risks of P&A operations** and **environmental emissions**. The reason for all these benefits is the use of rigless P&A operations enabled by using the shale as a barrier method.

The research group that is behind this concept is the Formation physics group in the Applied Geoscience department in SINTEF Industry. The Formation physics group study rock mechanics and rock physics properties, parameters for reservoir and cap rocks. The group perform tests near in-situ conditions in specialised laboratories. We have also tailor-made models and tools to calculate rock mechanical and rock physical behaviour. The group has been active for more than 40 years and has over time worked very closely with the industry. In 2014 a publication was made on modelling of creep – time dependent deformation – of sedimentary rocks. This was the key to start the contact with the industry to further develop our experience from oil wells where shale-based (clay-based) formations has shown the tendency to creep towards the steel casing and form an impermeable barrier on the outside. A series of competence building research projects in the Research Council of Norway has developed the **scientific foundation for this concept**: **"Shale as a permanent barrier after well abandonment" (2015-2018)**, **"Logging shale barrier before well abandonment" (2016-2019)** and **"Shale barrier toolbox: Designing future wells for efficient completion and simpler P&A" (2018-2022)**. 75 MNOK in budget and a close collaboration with 9 participating oil companies (Equinor, AkerBP, ConocoPhillips, BP (UK), Lundin, Petrobras, Shell, Total and Vår Energi) has developed this concept over time.

Key researchers:
Erling Fjær, Chief Scientist. Link: https://www.sintef.no/en/all-employees/employee/erling.fjaer/
Idar Larsen, Senior project manager. Link:https://www.sintef.no/en/all-employees/employee/idar.larsen/
Jørn Stenebråten, Senior researcher. Link: https://www.sintef.no/en/all-employees/employee/jorn.stenebraten/

Key contextual information:

- Torbjørn Vrålstad et. al. 2019: Plug and abandonment of offshore wells: Ensuring long-term well integrity and cost-efficiency. Journal of Petroleum Science and Engineering (section 4.3). https://www.sciencedirect.com/science/article/pii/S0920410518309173
- Fjær, E., Stenebråten, J. F., Bakheim, S., Larsen, I. 2023: Characteristics features of shale barrier materials. Geoenergy Science and Engineering. https://www.sciencedirect.com/science/article/pii/S2949891023008990?via%3Dihub

3. References to the research

Key references for the scientific background:

Fjær, E., Stenebråten, J.F., Bakheim, S., Larsen, I., 2023: Characteristic features of shale barrier materials. Geoen Sci Eng, 231, 212312, Open access: https://doi.org/10.1016/j.geoen.2023.212312

Key output: In many wells, it has been observed that shale formations creep in and close the annulus around the well, thus creating shale barriers which may represent huge cost savings for the operator. This study has established a quantitative classification system for shales in terms of their willingness to form shale barriers. The classification reflects the fact that formation of a shale barrier is a process that depends not only on the rock itself but also on the *in-situ* stress conditions as well as borehole orientation. Application of this system on laboratory data reveals that porosity is a key parameter for classification of shale barrier materials. Clay content is less important if it is higher than a given threshold, while quartz content is less important if it is lower than a given threshold.

Xie, X., Bauer, A., Stenebråten, J.F., Bakheim, S., Lavrov, A., Fjær, E., Kristiansen, T.G., 2020: Can Heating Induce Borehole Closure? Rock Mech Rock Eng, 53, 5715–5744. Open access: Can Heating Induce Borehole Closure? | Rock Mechanics and Rock Engineering (springer.com)

Key output: In some shale formations, the rock creeps in and spontaneously form a sealing hydraulic barrier around a well. In other formations, this does not happen spontaneously. This study shows that borehole heating may trigger the annulus closure process which is a necessary condition for the formation of a hydraulic barrier. This suggests that borehole heating may potentially be considered as a novel substitution for conventional P&A operations.

Raaen, A.M., Fjær, E., 2020: Pressure testing of barrier integrity, 39th International Conference on Ocean, Offshore and Arctic Engineering, OMAE2020-18713.

Key output: In the field, the hydraulic integrity of well barriers is usually verified by pressure integrity tests. This study shows that such tests do not have the required accuracy needed to ensure that sealing integrity is restored, as specified by petroleum industry standards. The study also shows that temperature effects have the potential to invalidate the test results.

Fjær, E., Stenebråten, J.F., Bakheim, S., 2018: Laboratory test for studies on shale barrier formation, 52nd US Rock Mechanics / Geomechanics Symposium, ARMA 18-1146.

Key output: The study describes a specific laboratory test where shale samples are subjected to similar conditions as the rock around a well, enabling tests of their ability to establish sealing, natural barriers. Such tests reveal how the sealing efficiency of the barrier and the load on the casing develops with time. The test description sets a standard for how to characterize natural barrier materials.

Fjær, E., Stenebråten, J.F., 2016: How Shale May Form a Sealing Barrier around a Well, 5th EAGE Shale Workshop, Extended abstract. DOI: 10.3997/2214-4609.201600415

Key output: This abstract outline the principles of a study designed to establish necessary knowledge so that natural hydraulic barriers around wells can be fully utilized when the conditions allow for this.

Fjær, E., Larsen, I., Holt, R.M., Bauer, A. 2014: A creepy model for creep. 48th US Rock Mechanics/Geomechanics Symposium, ARMA 14-7398.

Key output: This paper describes the derivation of a mathematical model capable of describing transient creep as well as the complete sequence of transient, steady state and accelerating creep, including the transition between the stable and unstable regimes. The underlying conceptual model describes creep because of time-consuming localized failure events which may trigger

subsequent events elsewhere, resulting in a series of events that may either fade away asymptotically or at some point turn unstable and accelerate towards global failure.

4. Details of the impact

The concept of and development of using shale as a permanent barrier for well plugging has been a large **collaboration effort** between many **oil and gas operators** and **SINTEF/NTNU** (research institutes and universities) over many years. A rough estimate on the contribution from R&D institutions is as follows**: SINTEF Industry: 82%, SINTEF Digital: 5% and NTNU: 13%.** The contributions from SINTEF Digital have been designing and testing of a new laboratory scale acoustic system for logging through the steel casing and NTNU has educated 3 PhD's on topics such as modelling and simulation of creep in shales, acoustic logging through casing and designing future wells for efficient completion (experimental study).

The concept of using shale as a permanent barrier in well plugging and abandonment was first launched in 2014 with a paper on modelling of creep – time dependent deformation – of sedimentary rocks. This paper triggered a large interest among the operating oil companies, and we were able to run several development projects together with the industry to develop the scientific basis for this concept so that it can be implemented on a large scale globally.

In our first project on shale as a barrier, which was established to better understand the shale as a barrier concept, a numerical analytical tool was developed which was validated using measurements made in the laboratory under controlled conditions. In this and the following projects, one has been able to reproduce the observations made in the field, from scaled laboratory tests where one can directly compare verification information which is used in the field, both pressure tests and acoustic based measurements, so-called bond-logs. This has led the oil companies to a much better understanding and trust towards using shale as a barrier, when wells are plugged and abandoned. This work shows that shale as a barrier, when verified correctly, can have a much better ability to seal than today's methods using cement. This concept has a large potential for cost reductions and reduced operational risks as well as reduced environmental impact due to rigless P&A. All though the shale as a barrier concept has been used in the past based on logging and verifying the presence of creeping formations in every well, the scientific fundament brought forward by SINTEF has led to a predictive tool which can be used for a large-scale implementation of the shale as a barrier concept. The industry has already used this knowledge to improve their P&A processes and has experienced a large impact on costs, HSE and safety as stated from Norway's 3 largest oil companies below.

Statements are deleted.

4

5. Sources to corroborate the impact

Impact statements from Norway's 3 largest oil and gas companies, contacts are:

- Truls Carlsen, Specialist Drilling and Wellbore Stability – Equinor.
  E-mail: trcar@equinor.com
- Tron Golder Kristiansen, Chief engineer Drilling & Well – Rock mechanics – AkerBP
  E-mail: tron.golder.kristiansen@akerbp.com
- Pauline Otreba, Principal R&D Engineer – Vår Energi
  E-mail: pauline.elizabeth.otreba@varenergi.no

5

SINTEF Industry Case number 4

Institution: SINTEF AS
Administrative unit: SINTEF Industry
Title of case study: Hydrogen research in SINTEF Industry
Period when the underpinning research was undertaken: 1990-2022
Period when staff involved in the underpinning research were employed by the submitting institution: Staff was employed during the period from 1988 until 2018
Period when the impact occurred: 2012-2022

1. Summary of the impact

In transitioning from a fossil-based to a renewable energy economy, we face several challenges related to energy storage. Electricity generation from renewable sources is intermittent, and usually not coordinated with demand. To be able to utilize the generated electricity, efficient and sustainable energy storage solutions are needed. A combination of solutions will be necessary, and hydrogen will be one of the major pieces in the energy storage puzzle, and as such, needs to be a vital part of our national and international decarbonization strategy. SINTEF regards hydrogen as one coherent, though multi-faceted topic, and believes that our research and development of technologies in all parts of the value chain is crucial in our quest for a zero-emission society.

SINTEF Industry (SI) has been involved in research into hydrogen technologies for more than 30 years. The main focus has been on fuel cells and electrolyzers, but also other aspects of the hydrogen value chain, such as hydrogen membranes, hydrogen embrittlement of metallic materials in transport infrastructures and use of hydrogen in the metallurgical industry. We have contributed to the development of new IP and scientific understanding, multiple new industrial actors and promotion and implementation of hydrogen as an energy carrier. The activity has been funded by the EU mainly through the Fuel Cells and Hydrogen Joint Undertaking/Clean Hydrogen Partnership, by the Research Council of Norway (RCN) and through direct projects with industry.

2. Underpinning research

Since 2012, SI has been represented at the Executive Board of Hydrogen Europe Research and was also one of the founders of EERA's Hydrogen Europe Research. On a national level, SINTEF has Chaired the Board for the Norwegian Hydrogen Forum from 2015 to 2023. Through the above engagements, SINTEF has contributed to shaping the political agenda and priorities for R&D funding both in Europe and nationally through active participation in development of roadmaps and call topics. SI is also contributing to all aspects of the FME on hydrogen, HYDROGENi.

SI has coordinated a number of EU projects on electrolysis technologies spanning from low temperature water-based technologies (Alkaline electrolysis (AEL), proton exchange membrane electrolysis (PEMEL), anion exchange membrane electrolysis (AEMEL)) to high temperature steam-based technologies (solid oxide electrolysis (SOEL) and proton conducting ceramic electrolysis (PCCEL)), progressing the Technology Readiness Level (TRL) of these technologies from TRL2 to TRL9. This is illustrated with the development of PEMEL, with projects initially focusing on materials development (Nexpel), system design (Novel) via up-scaling (MegaStack) to demonstration up to MW scale (Refhyne, Refhyne II), building competence, technology and intellectual property. Similar evolution is undertaken with the development of PCCEL technology for pressurized hydrogen production from 2014 and onwards, with the development of materials (ELECTRA), manufacturing production, cell and first stack design (GAMER), multiscale modelling (WINNER) and upscaled system demonstration (PROTOSTACK). The work on PCCEL technology led by SI led to publication of 9 Innovations published by the European Innovation Radar platform, with 7 associated with SI.

Our focus in the low temperature fuel cell area has been on diagnostics and prognostics of fuel cells (Giantleap), in collaboration with leading companies such as Ballard, Hydrogenics/Cummins, Bosch Engineering, ElringKlinger and VDL. Degradation of PEM fuel cells and the effect of various contaminants in the hydrogen fuel are in SI's central research areas to promote the implementation of fuel cells in society. In 2012 we executed our first hydrogen fuel quality control project as part of the H2Moves Scandinavia demonstration project. Since then, key projects like HyCoRA, Hydraite, MetroHyVe 1&2 have further disseminated dispensed fuel quality as well as performed key investigations of the impact of impurities on fuel cell systems.

Since 1990 SINTEF Industry has conducted pioneering and extensive research on unique Pd-membranes that can be integrated with supports in various configurations. Last 10 years, research has improved insight about properties and how to scale up the manufacturing. Cooperation with NTNU and international industry and research institutes has fruitfully supported the broadly published research > 20 journal papers and 5 book chapters. In 2017 the Norwegian company Hydrogen Mem-Tech AS (HMT) was established licensing patented SI Pd-membrane technology. SI has cooperated with HMT in their effort to scale up the technology through R&D projects supported by CLIMIT Demo and RCN.

In the span of 2012-2022, six projects, supported by RCN funding (HIPP, HyFLEX, DEEPIT and ROP, funded by the Petromax program, HyLINE funded by CLIMIT/EnergiX, and the SMART-H infrastructure funded through FORINFRA), have employed multi-scale and multi-physics research to understand the interaction between hydrogen and metals such as: H uptake and diffusion, H influenced material, mechanical, fracture and fatigue properties. These efforts have yielded a comprehensive knowledge base, crucial for ensuring safe design and operation of subsea infrastructure dedicated to hydrogen transport.

Hydrogen in metal production is getting more and more attention as the industry needs to stop/reduce the use of fossil carbon as reducing agent or as fuel and thereby eliminate or reduce CO_2 emissions. SI has for the last 15 years established and been involved in projects that lay the theoretical and experimental foundation for hydrogen as an alternative reducing agent. Starting with internal projects that have resulted in both several national competence and innovations projects as well as EU funded projects (NatGasMetal, KPN GassFerroSil, Researcher project SiH_2, KPN Reduced CO_2, EU HARARE, FME HYDROGENi, EU H2Glass). The industrial partners have mainly been Norwegian non-ferro industry, however SI also cooperates with international steel companies targeting CO_2 free steel production.

Central research scientists:

Low temperature fuel cells and electrolyzers
Magnus Thomassen, Research Scientist/Sr. Research Scientist/Research Manager (2012-2021)
Alejandro Oyarce Barnett, Research Scientist/Sr. Research Scientist (2014-2021)
Kyrre Sundseth, Sr. Research Scientist/Research Manager (2017-2022) Kyrre Sundseth
Luis Colmenares Rausseo, Research Scientist/Sr. Research Scientist (2012-2016 and 2021-2022) Luis Cesar Colmenares Rausseo
Steffen Møller-Holst, Vice President – Marketing (2012-2022) Steffen Møller-Holst
Anders Ødegård, Research Scientist/Sr. Project Manager (2012-2022) Anders Ødegård
Thor Anders Aarhaug, Sr. Research Scientist (2012-2022) Thor Anders Aarhaug
Frode Rømo, Sr. Research Scientist/Research Manager (2018-2022) Frode Rømo

High temperature fuel cells and electrolyzers, Pd membranes
Thijs Peters, Sr. Research Scientist (2012-2022) Thijs Peters
Marie-Laure Fontaine, Sr. Research Scientist/Research Manager (2012-2022) Marie-Laure Fontaine
Marit Stange, Research Scientist/Sr. Research Scientist (2012-2022) Marit Stange
Rune Bredesen, Research Director (2012-2022) Rune Bredesen
Yngve Larring, Sr. Research Scientist (2012-2022) Yngve Larring

Per Martin Rørvik, Research Scientist/Sr. Research Scientist (2012-2022) Per Martin Rørvik
Luca Ansaloni, Research Scientist/Sr. Research Scientist (2018-2022) Luca Ansaloni
Einar Vøllestad, Research Scientist/Sr. Research Scientist (2018-2022) Einar Vøllestad

Hydrogen embrittlement
Vigdis Olden, Sr. Research Scientist (2012-2022) Vigdis Olden
Bård Nyhus, Sr. Research Scientist (2012-2022) Bård Nyhus
Antonio Alvaro, Research Scientist/Sr. Research Scientist (2012-2022) Antonio Alvaro

Hydrogen as a fuel/reducing agent in metallurgical industry
Halvor Dalaker, Sr. Research Scientist (2012-2022) Halvor Dalaker
Eli Ringdalen, Sr. Research Scientist (2012-2022) Eli Ringdalen
Martin Syvertsen, Sr. Research Scientist (2019-2022) Martin Syvertsen

3. References to the research (references on various aspects of our hydrogen research)

1) **V. Olden, A. Alvaro**, **O.M. Akselsen**, *Hydrogen diffusion and hydrogen influenced critical stress intensity in an API X70 pipeline steel welded joint-Experiments and FE simulations*, International Journal of Hydrogen Energy, 2012, doi: 10.1016/j.ijhydene.2012.05.005
2) P. Marocco, D. Ferrero, M. Gandiglio, **M.M. Ortiz**, **K. Sundseth**, A. Lanzini, M. Santarelli, *A study of the techno-economic feasibility of H_2-based energy storage systems in remote areas,* Energy Conversion and Management, 2020, doi: 10.1016/j.enconman.2020.112768/
3) **E. Vøllestad**, **R. Strandbakke**, M. Tarach, D. Catalán, **M.-L. Fontaine**, D. Beeaff, D. R. Clark, J. M. Serra, T. Norby, *Mixed Proton and Electron Conducting Double Perovskite Anodes for Stable and Efficient Tubular Proton Ceramic Electrolysers*, Nature Materials, 2019, doi: 10.1038/s41563-019-0388-2
4) T. Bacquart, A. Murugan, M. Carré, B. Gozlan, F. Auprêtre, F. Haloua, **T. A. Aarhaug**, *Probability of occurrence of ISO 14687-2 contaminants in hydrogen: Principles and examples from steam methane reforming and electrolysis (water and chlor-alkali) production processes model*, International Journal of Hydrogen Energy, 2018, doi: 10.1016/j.ijhydene.2018.03.084
5) **P. Fortin**, T. Khoza, X. Cao, **S.Y. Martinsen, A.O. Barnett**, S. Holdcroft, *High-performance alkaline water electrolysis using Aemion™ anion exchange membranes*, Journal of Power Sources, 2020, doi: 10.1016/j.jpowsour.2020.227814
6) **H. Dalaker**, **E. Ringdalen**, L. Kolbeinsen, J. Mårdalen, *Roadmap for gas in the Norwegian metallurgical industry: greater value creation and reduced emissions*, SINTEF report 2017
7) **T.A. Peters**, **P.M. Rørvik**, **T.O. Sunde**, **M. Stange**, F. Roness, T.R. Reinertsen, **J.H. Ræder**, **Y. Larring**, **R. Bredesen**, *Palladium (Pd) Membranes as Key Enabling Technology for Pre-combustion CO2 Capture and Hydrogen Production*, 2017, doi: 10.1016/j.egypro.2017.03.1144

4. Details of the impact

SI's efforts towards the political arena in the EU has benefited both Norwegian industry and the research community. SI has provided Norwegian stakeholders with a direct channel for influencing the European partnership's annual call for proposals. This interaction has also contributed to conveying Norwegian interests and influence the European priorities in this direction. SI has since 2012 been a partner in 38 EU-projects and coordinated more than 20 of these. We have also taken on the coordination role of larger demonstration projects, the two largest ones (REFHYNE, REFHYNE II) with total budgets exceeding 100 M€. The REFHYNE project (Clean Refinery Hydrogen for Europe) is developing what will be one of the largest PEM electrolyzer plants in the world.

Our activities on the development of electrolysis technology have resulted in major developments on the industrial arena, e.g. through the series of EU projects on PEMEL, with the technology that was the foundation for the establishment of the SI Spin-off Hystar in 2021. Similarly, on the PCCEL side, our efforts have contributed to the implementation of the company Protia AS (now CoorsTek Membrane Sciences), later acquired by CoorsTek, one of the main worldwide producers of ceramic materials. CoorsTek Membrane Sciences has since then, launched a portfolio of projects (with

private own capital as well as co-funding with industries, and with national and European funding) to develop and deploy proton ceramic based electrochemical technologies, where SI has a central role in materials research and validation. CTMS and SI have also co-funded and share joint laboratories for prototype manufacturing of cells and advanced testing in ammonia laboratory launched in 2022.

On the fuel cell side, we have established a close working relationship with the large actors in Europe and Norway, and contributed to increased understanding on degradation mechanisms, lifetime predictions, degradation mitigation strategies, and the effect of impurities on lifetimes and degradation. We have also established standards and protocols for hydrogen gas purity measurements and have provided expert contributions and leadership to international standardization processes. SI has been central in the standardization work defining fuel specification, quality control and sampling, and contributed to the development of standards like ISO 14687, ISO 19880-8, EN 17124. Also, based on significant experience with inline identification of degradation mechanisms and development of mitigation strategies on multiple time scales for PEM fuel cells, SI will be capable of providing guidelines also for electrolyzer operation optimization. By linking this mechanistic competence to techno-economic modelling, this proves a solid basis for optimizing the profits from operating the electrolyzer plants.

SI is also heavily engaged in development and implementation of fuel cell and hydrogen technologies in Norway. SI provides scientific based decision support to leading Norwegian industry companies like grocery wholesaler ASKO (heavy duty trucks and forklifts) and several companies establishing hydrogen systems and infrastructure; e.g., Technip FMC (Deep Purple; offshore hydrogen production/subsea storage), Norwegian Hydrogen AS (Hellesylt Hydrogen Hub), H2Marine (Ubåt), Aneo (REMOTE) and VarangerKraft (Haeolus) in technology selection, dimensioning, value chain assessment from power requirements upstream, H2-demand and logistics, potential use of oxygen and excess heat system design as well as strategic positioning. SI have provided scientific excellence by combining software and hardware parts for designing and optimising PEM fuel cells and battery hybrid systems (e.g. Virtual-FCS for transport applications). Through coordination of the multi-national hydrogen safety research projects SH2IFT 1 and 2, SI has acquired general competence relevant for discussions of safety aspects of system solutions and concepts.

The impact of the extensive Pd-membrane research work has materialised by the licensing agreement and establishment of the company Reinertsen AS (later HMT) in 2017 based on the SI technology. In May 2022 HMT received in an investment of 170 MNOK from large international actors such as Yara, Shell, Saudi Aramco and AP Ventures for further strengthening the commercialization of the technology. Furthermore, to support the Pd-membrane technology development within Shell (NL), Tokyo Gas (JP) and TNO (NL) SI has made extensive investigations in multiple operations conditions by applying our competence and advanced technology.

The performed research on hydrogen embrittlement on subsea gas infrastructure are of pivotal importance for safe design, operation and repair, as it provides a knowledge base for the development of standards and guidelines. Direct beneficiaries are subsea infrastructure operators, energy companies and fabricating companies. A decision regarding reuse of existing subsea natural gas pipelines for hydrogen transport leans heavily on a solid knowledge base of the influence of hydrogen on the integrity of the pipelines including the welded joints.

The impact of using H2 as a reducing agent as an alternative to carbon for metal oxides is directly linked to reduction in CO_2 emissions from the metal production. This still requires extensive research to bring the technology from typically TRL 2-4 as is the status today. However, for some oxide-systems as ilmenite reduction at INEOS Tyssedal, pre-reduction of manganese (Eramet Norway), and direct reduction of iron-ores (ex Hybrit Sweden) the use of hydrogen is approaching the implementing phase. Preliminary studies at SI have also shown that Hydrogen in the form of plasma is promising and can overcome the thermodynamic challenges that hydrogen has as compared to carbon as reducing agent.

5. Sources to corroborate the impact

Hystar – Alejandro Oyarce Barnett and Magnus Thomassen

The SINTEF spinoff Hystar has developed a unique, patented electrolysis technology that will make green hydrogen production cheaper. The core of the new technology is about the development of a new PEM, reducing the energy-intensive process required to produce hydrogen with renewable power. In collaboration with SI, Hystar's technology has been verified over several thousand hours of testing through use of SI research infrastructure, supported by modelling activities, to enable large scale hydrogen production.

ASKO – Jørn Arvid Endresen

The logistics company ASKO has worked actively for several years to reduce greenhouse gas emissions. As part of this work, ASKO Midt-Norway is the first company in the Nordic region to use hydrogen-powered trucks linked to the regional warehouse in Trondheim. Since its inception in 2015, SI has contributed to the realization of this.

Coorstek Membrane Sciences (CTMS) – Per Kristian Vestre

CTMS is developing high temperature electrochemical processes to produce hydrogen from various streams (Hydrocarbons, ammonia, steam) with high efficiency and low carbon footprint. SI has contributed to CTMS growth through collaboration in multiple joint projects and co-funding/ sharing of laboratories at Oslo. Joint research efforts have also contributed to the establishment of several innovations recognized by the European Commission Innovation Radar platform.

Hydrogen Mem-Tech (HMT) – Thomas Reinertsen

HMT is developing hydrogen Pd-based membrane separation technology based on licensed SI technology. The technology has received large interest from major companies in fields of production and use of hydrogen through investments in the company, see e.g.: (Norwegian cleantech company collects €16M for its palladium membrane technology - ArcticStartup). Currently HMT employs 15 people and aims at hydrogen production from ammonia and natural gas with carbon capture.

Shell Amsterdam – Arian Nijmeijer

Shell has collaborated with SI on Pd-membrane technology and to develop proton ceramic based electrolyzers since 2016 through consecutive direct projects (Cerhyec I, II, III, LOWPCE) and participation in European projects (GAMER, WINNER, PROTOSTACK). They have led efforts on multi-scale multi-physics modelling and system development of the PCCEL technology. This has contributed to the establishment of two innovations recognized by the European Commission Innovation Radar platform.

Technip FMC – Andreas Løvli

Et steg nærmere grønn omstilling offshore - SINTEF

SI started collaborating with TechnipFMC in 2016. Since then, SI has contributed to concept development, analyses, optimization tools, adaptation of electrolyzers to marine conditions, testing of pressurized tanks and couplings, and understanding of technology. Expertise in hydrogen technology and system solutions has been built through a number of projects over several years. This knowledge will be important in the future scale-up, implementation and use of this technology.

Equinor – Mons Hauge and Lars Magne Haldorsen

The phenomenon recognized as "Hydrogen Embrittlement" (HE) is one of the concerns when utilizing the existing natural gas pipeline network for hydrogen transport. HE leads to loss of mechanical ductility, reduced fracture toughness and degradation of fatigue properties.
To investigate these effects, Equinor has participated in various research projects since 2012 on the influence of hydrogen on metallic materials. These projects have been supported by The Research Council of Norway and have contributed to the understanding of HE as basis for industrial solutions and improved design criteria for hydrogen storage and transport infrastructure.

SINTEF Manufacturing AS, impact case 1

Institution: SINTEF Manufacturing AS
Administrative unit: SINTEF Manufacturing AS
Title of case study: SFI Manufacturing
Period when the underpinning research was undertaken: 2008-2023
Period when staff involved in the underpinning research were employed by the submitting institution: 2008-2023
Period when the impact occurred: 2018-2022

1. Summary of the impact (indicative maximum 100 words)

This case study is based on the activity of SFI Manufacturing throughout the centre period 2025-2023. SINTEF Manufacturing has been the host institution of SFI Manufacturing, and the research has been executed as a collaboration with NTNU, two other SINTEF institutes and 14 Norwegian manufacturing companies. The present case study is focused on development of a research based innovation model, research activities and impacts where SINTEF Manufacturing has been the key institution for execution. The work based on this model has resulted in innovation projects with a total budget of 790 million NOK over the period 2016-2022. The potential direct economic impact of these innovation projects has been calculated to be an increased annual revenue of more than 3 billion NOK from 2026, in addition these projects will have impact on reduced operating costs, increased profits and reduced investments. More than 50 companies participate in these projects and benefit from this impact. The impact of the research activity also includes education of 16 PhD's, 4 post docs and more than 50 MSc's. In all, the impact of SFI Manufacturing contribute to further development of sustainable manufacturing in Norway.

2. Underpinning research (indicative maximum 500 words)

SFI Manufacturing has been a cross-disciplinary centre for research based innovation for competitive high value manufacturing in Norway. The centre has focused on, Multi-material products and processes, Robust and flexible automation, and Innovative and sustainable organizations. The research has provided a knowledge base for further innovation and development of sustainable manufacturing in Norway. The knowledge base covers both materials technology, automatization/digitalisation and organisational science.

The research has been a collaborative activity between the academic and industrial partners within the centre. SINTEF Manufacturing has been the leading partner for developing and facilitating the activities in the research based innovation model of the centre. In addition, SINTEF Manufacturing has been key institution within the research on mulit-material joining, additive manufacturing, use of recycled materials in high end products, robust and cost-efficient approaches for assembly of products in low volumes and many product variants, constraint-based robot programming, and organizational and innovative sustainability aspects of advanced manufacturing companies.

Part of this research in SINTEF Manufacturing started back in 2008 and has been a continues activity the whole period up to 2023. Innovation associated with this research comes from the value chain of 1) our research, 2) spin-off projects and 3) new initiatives and activities.
Our spin-off projects are an important arena for the transfer of knowledge from the centre to the partners, and feedback from the partners to the centre, for example regarding potential revision and modification of research topics throughout the period.

Key researchers in SINTEF Manufacturing during the period 2008-2023:

- Vegard Brøtan, Research Manager
- Sverre Gulbrandsen-Dahl, Chief scientist
- Gabor Sziebig, Research Manager, 2019-dd
- Gaute Knutstad, Research Manager, 2018-2021
- Sigurd Sagen Vildåsen, Senior Research Scientist, 2018 - 2022
- Kristian Martinsen, Senior Business Developer, 1997 - 2019 & 2021-dd
- Ådne S. Linnerud, Research Scientist
- Kjersti Øverbø Schulte, Senior Research Scientist
- Eirin Lodgaard, Senior Research Scientist
- Daryl Powell, Chief scientist, 2019-dd
- Tone Beate Gjerstad, Research Manager, 1998-2020
- Siri Marthe Arbo, Research Scientist, 2019-dd
- Mathias Hauan Arbo, Research Scientist, 2019 & 2021-dd

3. References to the research (indicative maximum of six references)

Authors: K. Martinsen, S. Gulbrandsen-Dahl
Title of work: Use of Post-consumer Scrap in Aluminium Wrought Alloy Structural Components for the Transportation Sector
Book/compendium/journal: Procedia CIRP
Page no.: 686–691
Issue/Volume/Year: 29/2015
ISSN/ISBN: 2212-8271
Link: http://www.sciencedirect.com/science/article/pii/S2212827115001158

Authors: J.L. Duigou, S. Gulbrandsen-Dahl, F. Vallet, R. Söderberg, B. Eynard, N. Perry
Title of work: Optimization and Lifecycle engineering for Design and Manufacture of Recycled Aluminium Parts
Book/compendium/journal: CIRP Annals - Manufacturing Technology
Page no.: 149-152
Issue/Volume/Year: 1/65/2016
ISSN/ISBN: 0007-8506
Link: https://www.sciencedirect.com/science/article/pii/S0007850616301111

Authors: O. Hoem, E. Lodgaard
Title of work: Model for supporting lasting managerial efforts in continuous improvement: A case study in product engineering
Book/compendium/journal: Procedia CIRP, 26th CIRP Design Conference
Page no.: 38 -43
Issue/Volume/Year: 50/2016
Link: https://www.sciencedirect.com/science/article/pii/S2212827116304735

Authors: L.D. Evjemo, S. Moe, J.T. Gravdahl, O. Roulet-Dubonnet, L.T. Gellein, V. Brøtan
Title of work: Additive manufacturing by robot manipulator: An overview of the state-of-the-art and proof-of-concept results.
Book/compendium/journal: 22nd IEEE International Conference on Emerging Technologies And Factory Automation 2017
Issue/Volume/Year: 1/2017
ISSN/ISBN: 1946-0759
Link: https://ieeexplore.ieee.org/document/8247617

Authors: O. Semeniuta, S. Dansfeld, K. Martinsen, P. Falkman

Title of work: Towards increased intelligence and automatic improvement in industrial vision systems
Book/compendium/journal: Procedia CIRP
Page no.: 256-261
Link: https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/2493531

Authors: A.A. Transeth, A. Stepanov, Å.S. Linnerud, K. Ening, T.B. Gjerstad,
Title of work: Competitive high variance, low volume manufacturing with robot manipulators
Book/compendium/journal: Proceedings of 3rd International Symposium on Small-scale Intelligent Manufacturing Systems (SIMS)
Page no.: 1-7
Issue/Volume/Year: 2020
Doi: 10.1109/SIMS49386.2020.9121464
Link: https://sintef.brage.unit.no/sintef-xmlui/bitstream/handle/11250/3057392/Transeth_2020_Competitive_high_AAM.pdf?sequence=4&isAllowed=y

4. Details of the impact (indicative maximum 750 words)

As host institution for SFI Manufacturing, SINTEF Manufacturing has been the responsible for dissemination activities dedicated for our industrial partners within the centre. In this work have utilised 3 main tools: 1) annual 1-1 meetings with each of the 14 industrial partners where we have presented updated and tailored information regarded recent research within the centre and international trends, and where the industrial partners have given us insight into their present issues regarding manufacturing challenges. 2) 3 workshops annually with all industrial and academic partners with alternating topics from the research activities. 3) Individual case activities at the industrial partners where research based knowledge is implemented into ongoing development activities within the company.

In 2018 SINTEF Manufacturing initiated a new action regarding the stimulation of knowledge transfer within SFI Manufacturing: A schematic overview of all results from 2015 to 2018. This overview includes a description of the problem, research methodology, presented results and further plans. The development on TRL-scale and link to spin-off projects is included as well. Based on this overview, all partners may now have an insight into all activities, status and where to find more information. This overview has been updated annually providing close to real-time insights.

SFI Manufacturing has had an important role as incubator for spin-off projects, such as user driven innovation projects (supported by the Research Council of Norway) and collaborative projects (supported by the European Commission). The centre's ambition was to generate a portfolio of spin-off projects with a total budget of 800 million NOK, over the 8-year centre period. SINTEF Manufacturing has created a process model for the development and implementation of new project ideas, to ensure the complementarity and relevance of the research throughout the centre's period. In the period 2016-2019, we had succeeded to establish a total activity exceeding 80% of the ambition of the 8-year period. In addition, all SFI partners are also partner in one or more of the spin-off projects. In addition, more 30 other manufacturing companies were involved in these spin-off projects. Our spin-off projects are an important arena for the transfer of knowledge from the centre to the partners, and feedback from the partners to the centre, for example regarding potential revised research themes. This knowledge transfer is achieved through the direct link between the centre's activities and spinoff projects, for example via researchers and PhD candidates.

Examples reported impacts from our industrial partners in SFI Manufacturing:

- Kongsberg Automotive: New product, new processes, recruitment
- Benteler Automotive Systems: New processes, recruitment
- Nammo Raufoss: New product, recruitment, new organisational process
- Mjøs Metallvarefabrikk: New product
- Brødrene Aa: New product concept, new organisational process
- Kongsberg Maritime: New process, new business model
- Plasto: New process
- Hexagon Ragasco: New product

SINTEF Manufacturing has been involved in more than 60% of all these spin-off projects. Hence, a considerable amount of the activity has also been beneficial for the other academic partners within SINTEF and NTNU.

During the period 2016-2022 SINTEF Manufacturing has employed 2 of the PhDs educated in SFI Manufacturing and one professor from NTNU as scientific researcher and business developers. They do partly continue their research from the SFI and partly been active in implementing results at our industrial partners.

SINTEF Manufacturing has taken the lead in writing two white papers from SFI Manufacturing: 1) Input to the Norwegian Governments white paper on industry policy: Tools from Idea to Producible Product. 2) The Trends that Will Shape Norwegian Manufacturing in the Next 10 Years. The first white paper seemed to have influence on the resulting Meld. St. 27 (2016–2017) A greener, smarter and more innovative industry. One of these aspects was establishing a new funding scheme for Norwegian Catapults. This scheme was launched in 2018 and Manufacturing Technology (initiated by SINTEF Manufacturing) was 1 of the 5 funded catapult centres in Norway.

5. Sources to corroborate the impact (indicative maximum of ten references)

Annual reports of SFI Manufacturing: https://www.sfimanufacturing.no/annual-reports.html

White paper on industry policy: https://www.sfimanufacturing.no/white-paper-on-industry-policy.html

White Paper: The Trends that Will Shape Norwegian Manufacturing in the Next 10 Years: https://www.sfimanufacturing.no/white-paper-on-manufacturing-trends.html

Potential economic impact of SFI Manufacturing: https://www.sfimanufacturing.no/blog/potential-economic-impact-of-sfi-manufacturing-gt3-billion-nokyear

SINTEF Manufacturing AS, impact case 3

Institution: SINTEF Manufacturing AS
Administrative unit: SINTEF Manufacturing AS
Title of case study: Quick Response 4.0
Period when the underpinning research was undertaken: 2020-2023
Period when staff involved in the underpinning research were employed by the submitting institution: 2020-2023
Period when the impact occurred: 2020-2023

1. Summary of the impact (indicative maximum 100 words)

Goal: Increase the value chain responsiveness of SME manufacturers of customised products. **Results: 77% lead time reduction, 50% waste reduction, doubling of earnings before interest, tax, depreciation, and amortisation (EBITDA), 30% increase in turnover; 4000m^2 reduction of used area.**

HOW: develop tools & solutions based on Lean, Quick Response Manufacturing (QRM) and Industry 4.0, for: Modelling the material and information flows in the value chains and identifying bottlenecks (e.g. in https://doi.org/10.1016/j.procir.2021.11.228); Automatic optimisation of production planning and levelling, experience-based (e.g. in https://doi.org/10.1007/978-3-031-38165-2_20), ABC-XYZ inventory classification for quick response production, and a model for Monte Carlo simulation of replenishment methods for short lead times (https://hdl.handle.net/11250/2788805), Digital twin of the value chain to estimate production volume and lead times, and to monitor the equipment health (https://github.com/SINTEF-9012/SINDIT and https://ieeexplore.ieee.org/document/9779654), Software for optimisation of pallet packing (https://github.com/SINTEF/rr-pallet-packing-dash and https://github.com/SINTEF/rr-pallet-packing-real-backend)

2. Underpinning research (indicative maximum 500 words)

The Quick Response 4.0 project started in March 2020. Descriptions in both Norwegian and English can be found on the project's website: https://www.sintef.no/en/projects/2020/quick-response-4.0/. Quick Response Manufacturing (QRM) is a strategy that can take Lean, Six Sigma and Total Quality Management to the next level, for companies with high customization requirements. In Norway, there are many companies operating in this segment. By help of QRM, many European and international companies have reduced their lead times by up to 90%. At the same time, they have improved product quality and reduced production costs. Universities such as Wisconsin-Madison in the USA (https://qrm.engr.wisc.edu/) and HAN in the Netherlands (https://specials.han.nl/sites/lean/), as well as the QRM centre in Denmark (https://www.qrmdanmark.dk/) showcase such results. As of today, there is little published about QRM in Norway, although several companies are interested in the topic. Both QRM and Industry 4.0 place special emphasis on streamlining the information flows. Industry 4.0 technologies can enable a virtually seamless flow of information throughout the value chain, and thereby digitally enhance a Quick Response strategy. The R&D work in 2022-2023 included testing and further development of methods and tools for implementing the Rapid Response 4.0 concept in the value chain, which include: (i) methods and software for automated production planning and for levelling of production with high demands for customization and short lead times, (ii) inventory planning and management method consisting of a tool for ABC-XYZ product classification for rapid response production, and a model for Montecarlo simulation of replenishment methods for increased resource and cost efficiency, and (iii)

software for real-time optimization of pallet packing and for evaluation of the cost-benefit, based on advanced analysis of RFID sensor data from production and on machine learning.

- The key researchers at the administrative unit at the time of the research were Maria Flavia Mogos (Senior researcher, project manager); Daryl Powell (chief scientist); Eirin Lodgaard (Senior researcher); Torbjørn Leirmo (researcher); Eivind Reke (Senior advisor).

3. References to the research (indicative maximum of six references)

This section should provide references to key outputs from the research described in the previous section, and evidence about the quality of the research. All forms of output cited as underpinning research will be considered equitably, with no distinction being made between the types of output referenced. Include the following details for each cited output:

- Powell, Daryl; Romero, David; Gaiardelli, Paolo (2022) New and Renewed Manufacturing Paradigms for Sustainable Production. Sustainability. 14(3). DOI: 10.3390/su14031279
- Powell, Daryl John; Lodgaard, Eirin Anita; Mogos, Flavia Maria (2021) Quick-Scan – Towards a Strategy for Quick Response Manufacturing 4.0. Procedia CIRP. DOI: 10.1016/j.procir.2021.11.228
- Langedahl Leirmo, Torbjørn; Mats Larsen; Flavia Mogos , Maria (2023) Scheduling in Flexible Manufacturing Systems: A Case Study for Production Levelling Under Volume Constraints. Lecture Notes in Mechanical Engineering. DOI: 10.1007/978-3-031-38165-2_20

4. Details of the impact (indicative maximum 750 words)

Quick Response 4.0's main goal was to develop and implement innovative solutions for smart and sustainable *quick response* value chains for customized windows and doors, with the aim of reducing the value chain's costs by up to 40% and lead times by up to 90% compared to the current level (2019). The innovative solutions in the project will also show other SME manufacturers of customized goods how they can cost-effectively and sustainably develop the entire value chain to Quick Response and Industry 4.0 level, thereby strengthening their competitiveness on both the national and international markets. The main aim of the R&D work is to develop and test the knowledge base the project provides for innovation and improvement. To achieve the main goal, the following R&D sub-objectives must be achieved:

1. **Method for the developing a Quick Response 4.0 value chain strategy**: develop and test a method for designing value chain strategies for quick response production of high-quality customer-tailored goods, which is based on principles and methods in digitization (incl. circular economy) and considers the need for efficient coordination in a value chain consisting of customers, suppliers, distributors and own factory. The model aims to strengthen the value chain actors' competitiveness on both the national and international markets.
2. **Method for implementing Quick Response 4.0 in the factory**: develop and test new methods for production logistics that ensure efficient flow of materials and information in the factory (from receipt of goods to shipping of finished processed products) based on principles and methods within rapid response production and digitization (incl. circular economy).
3. **Method for digitized, quick response inventory planning and management**: develop and test a new inventory planning and management method based on principles and methods within quick response value chain management and digitization such as AI and AR for warehouse management (e.g. for space allocation depending on the type of transport unit and route). The method will facilitate a seamless flow of information between customers, suppliers, internal production and distributors using a sensor-based tracking system and will meet the requirement for increased flexibility to handle different customer requirements while maintaining the necessary resource and cost efficiency.
4. **Data-driven MMI platform with AI for Quick Response value chain**: develop and test an integrated decision support system for real-time monitoring of production in a value chain

consisting of customers, suppliers, distributors and own factory and warehouse, using a sensor-based tracking system and AI. The decision support system will facilitate the management of production orders and thus the prioritization of work orders, and will show production and inventory status, capture deviations and unexpected events, and support fast and efficient action and replanning throughout the entire chain. This will ensure efficient value creation both indoors and outdoors. This system will also meet the requirement for flexibility and efficient resource utilization in the value chain. For example, production processes can be quickly optimized and resource use reduced based on analyses of data from the tracking system.

5. Sources to corroborate the impact (indicative maximum of ten references)

See the project bank on the website of the research council of Norway:

https://prosjektbanken.forskningsradet.no/project/FORISS/310079?Kilde=FORISS&distribution=Ar&chart=bar&calcType=funding&Sprak=no&sortBy=date&sortOrder=desc&resultCount=30&offset=0&Organisasjon.3=GILJE+TRE+AS

SINTEF Manufacturing AS, impact case 2

Institution: SINTEF Manufacturing AS
Administrative unit: SINTEF Manufacturing AS
Title of case study: Learning as a tool for faster development of better, sustainable products (CIRCULAER)
Period when the underpinning research was undertaken: Q42020 – Q22023
Period when staff involved in the underpinning research were employed by the submitting institution: Q42020 – Q22023
Period when the impact occurred: Q42020 – Q22023

1. Summary of the impact (indicative maximum 100 words)

The project developed two industrial use-case demonstrators (demonstrating the effects of combining lean- and circular thinking) over the project period. The results were as follows:

Use-case 1: Laerdal Medical (LM):
Sales increased by 63% (for product family SimMan); Quality improved by 50%; Productivity increased by approx. 20%; 93% reduction of carbon footprint for packaging; 68% reduction of carbon footprint for Little Anne resuscitation doll.

Use-case 2: Haugstad Møbel (HM):
Turnover increased from 47 MNOK to 90 MNOK; Quality greatly improved (from no final inspection to down to zero external defects); Throughput time in the factory reduced from multiple weeks to just 4 hours; Products contain ca. 90% re-used materials.

2. Underpinning research (indicative maximum 500 words)

The research project was launched in October 2020. Throughout the project, both industry partners delivered a solid share of their own effort, which was a success factor for the implementation of the R&D results. The research underpinning the impact was transdisciplinary in nature and based on the action learning research methodology, a form of action research. This is a method in which the employees in the partner companies, together with researchers, developed and tested hypotheses for how lean thinking and circular economy can be used together in the development of circular business models, as well as more sustainable products and production processes. In addition, other methods were used for data capture, such as interviews and review of documents and company data.
Below is an overview of the central R&D activities (the project was divided into four main work packages):

H1. Towards Lean Circular Business Models: This activity was related to the research question "how can lean thinking and circular economy principles be combined?". In order to respond to this the circular value creation potential of the companies were mapped at the start of the project by use the "Value-uncaptured" framework. An LCA strategy was then developed. LM incorporated this in their self-developed support tool "ZeroAim". HM used the results in the development of new design strategy. Several workshops with both HM and LM were carried out in addition to a joint workshop in 2022 for sharing knowledge. A problem-based approach to development was used to test hypotheses on a small scale, further develop the most promising cases, and thus create new business opportunities based on the R strategies. The model that was developed in H1 has proved effective for both companies in systematizing

their development work in the effort to achieve the UN's sustainable development goals through increased circularity.

H2. Lean Circular Product (consisted of two main activities: 1. Development and implementation of the Obeya concept, 2. develop a concept for lean circular product development). One desired originally to implement the Obeya concept in a physical space. Because of. restrictions related to the coronavirus it was decided to test digital variants of the developed concept. This has, especially for LM's part, had a very positive effect on collaboration across functions and national borders. LM has therefore chosen to continue with the digital model of Obeya. Furthermore, in collaboration with managers in the product development departments and through several internal work meetings, developed a concept for lean circular product development. The work mainly consisted of testing different tools from design and lean product development to see if these could be used to uncover circular functionalities in addition to classic user functionalities. Examples of tools and methods that were tested are "Quality Function Deployment", "Concept Paper", "letter from the future" and "functional analysis". The results of this the work package was documented in two internal reports. HM has developed a new one in this work package design strategy for future product development. LM has adopted the findings in its own product development process and today uses variants of several of the methods that were tested in the project-

H3. Lean Circular Operations Management: The main activities in this work package have been systematic work on improving quality, productivity and footprint for production. Activities have been carried out both to develop and improve both internal and external logistics processes and production processes. In this work package it also has been a goal to include all employees in the work to implement these improvements. Essentially it is carried out workshops and working meetings at the "gemba" (where the value creation takes place). It is also completed study tours to both Sweden and Japan to study international best practice. The results of the activities are summarized in the model in the second section.

H4. Industrial Demonstrators (see section 1, above).

- The key researchers that represented the administrative unit during the research were Prof. Dr. Daryl John Powell (chief Scientist and Research Manager), Eivind Reke (Senior Advisor and project manager), Einar Hareide (Senior Advisor), and Johanne Sørumsbreden (researcher).

3. References to the research (indicative maximum of six references)

The results have been disseminated through book publications (1), journal articles (2), articles in conference proceedings (8), and popular science articles (3). A selection of outputs are listed below:

- Nujen, Bella B.; Kvadsheim, Nina Pereira; Mwesiumo, Deodat Edward; Reke, Eivind; Powell, Daryl (2023) Knowledge obstacles when transitioning towards circular economy: an industrial intra-organisational perspective. International Journal of Production Research. 61 (24). DOI: 10.1080 /00207543. 2022.2158243

- Reke, Eivind; Powell, Daryl John; Mogos, Flavia Maria (2022) Applying the fundamentals of TPS to realize a resilient and responsive manufacturing system. Procedia CIRP. 107, pp. 1221-1225. DOI: 10.1016/j. procir. 2022.05.135

- Reke, Eivind; Böhlmann, Nadja (2021) Developing Middle Managers with Gemba Training; Learning in the Digital Era: 7th European Lean Educator Conference, ELEC 2021, Trondheim, Norway, October 25–27, 2021, Proceedings; pp. 271-277. DOI: 10.1007 /978-3- 030- 92934- 3_27

- Mogos, Flavia Maria; Vildåsen, Sigurd; Sørumsbrenden, Johanne; Powell, Daryl John (2021) Rethinking Circular Business Models: The Role of the Learning Factory. Advances in Production Management Systems : Artificial Intelligence for Sustainable and Resilient Production Systems : IFIP WG 5.7 International Conference, APMS 2021, Nantes, France, September 5–9, 2021, Proceedings, Part III. Pp.402-410. DOI: 10.1007 /978-3- 030- 85906- 0_45

4. Details of the impact (indicative maximum 750 words)

Sustainable development in the form of lower emissions and an increased degree of circularity is essential for Norwegian industry to succeed in achieving the ambitious goals of the European Green Deal, which defines the EU's environmental strategy and circular economy plan with the aim of halving emissions by 2030, compared to 1990. To remain competitive, the Norwegian industry must therefore be able to develop new and better sustainable products and processes based on circular business models.

In the project "Learning as a tool for faster development of better, sustainable products" (Circulaer), Laerdal Medical and Haugstad Møbel in collaboration with SINTEF Manufacturing and Møreforsking have deployed lean thinking and practice as a business strategy, combined with circular economic principles, to develop more sustainable products and processes based on circular business models. Based on Lean's fundamental idea of replacing instruction and control with challenges and problem-solving, the project has, through action learning research, investigated how to engage and educate people, instead of controlling them, so that organizations can discover new ways to realize the opportunities that lie in an increased degree of circularity in the business model, product portfolio and operations.

During the project, specific hypotheses were developed and tested in rapid iterations that formed the basis for a new and innovative model for creating circular business models combining lean and circular economic principles. Furthermore, new product development methods and methods for developing more circular and thus more sustainable production processes were also developed and tested. A concept for cross-functional cooperation and interaction in product development, management, and production has also been developed and implemented. This concept has also been adopted in other companies that did not participate in the case project. Findings from the project have been presented in several conference articles, journal articles, and in popular science forms, and the findings will be a valuable contribution to the Norwegian industry's further work on sustainable transformation.

5. Sources to corroborate the impact (indicative maximum of ten references)

See project bank at The Research Council of Norway website:

https://prosjektbanken.forskningsradet.no/en/project/FORISS/313687?Kilde=FORISS&distribution=Ar&chart=bar&calcType=funding&Sprak=no&sortBy=date&sortOrder=desc&resultCount=30&offset=60&Prosjektleder=Jun%20Inoue

SINTEF Ocean – Case 1

Institution: SINTEF

Administrative unit: SINTEF Ocean

Title of case study: Exposed Aquaculture Operations

Period when the underpinning research was undertaken: 2015-2023

Period when staff involved in the underpinning research were employed by the submitting institution: 2015-2023

Period when the impact occurred: 2015 - ongoing

1. Summary of the impact

The Norwegian coast, with its remoteness and harsh weather conditions, poses many challenges to fish farming. The last decades, SINTEF Ocean has brought forward knowledge and technology that increase safety, efficiency and robustness of these operations. In 2015-2023, we had a center of research-based innovation dedicated to this: CRI Exposed Aquaculture operations. During these fast-paced times in the aquaculture industry, this was essential to identify and overcome challenges.

The activities in EXPOSED and surrounding projects have increased knowledge and resulted in a shared understanding across technological, biological, and societal research disciplines. The credit goes to a long-term partnership of world-leading companies and research institutions.

2. Underpinning research

In and around the research center EXPOSED (2015-2023), we have developed knowledge and technologies for robust, safe, and effective aquaculture operations. The research insights can be divided in these six areas:

Safety: Implementation of a risk assessment method that provides a comprehensive understanding and encourages employee involvement. This includes safety indicators, operational limits, interruption criteria, and an emergency preparedness plan tailored for construction, area, and industry-level needs.

Fish welfare: The research groups have gathered extensive knowledge about the swimming capacities of salmon and cleaner fish under various conditions. This information guides our site selection, routine operations, and technology use. In rough conditions, salmon have proven to cope well, moving deeper and away from nets when waves are large. The researchers have developed methods to understand stress, recovery, and energy levels, as well as behavior and speed. Additionally, a new fish tagging system and communication platform is introduced.

Robust structures and nets: Our understanding of waves and currents has increased, allowing us to create precise load models for nets and to develop technical standards for optimizing aquaculture farm design. The researchers have implemented a rating system to measure a site's exposure level, which improves management and site planning.

Safe vessel operations: We've established an analysis methodology to study movement between vessels and cages and to understand the impact on facilities and operational limits. Additionally, we've optimized logistics and developed a method for optimizing hull lines and vessel designs, specifically for exposed aquaculture.

Monitoring and decision support: Development of decision support tools for vessel operations and gaining an understanding of complex sensor systems to provide more precise environmental descriptions. Our modelling of aquaculture facilities includes vessel and cage interaction and prepares numerical simulations for tasks such as real-time wear and maintenance planning.

Autonomous systems: The developed technology and simulation tools allow for contact-free lifting operations. The researchers have automated cage inspection with the design of autonomous ROV operations for hole detection and maintenance. There also has been made advancements in navigation and localization of ROVs and AUVs relative to nets and flexible structures.

Overall, the research on exposed fish farming has directly improved technology and operational understanding, influencing suppliers, fish farmers, and shipowners, and have been shared with authorities and policy-makers. The researchers also have contributed to the development and revision of standards and guidelines.

International collaborations, including those with researchers from Norway, the Faroe Islands, and Australia, proved valuable. Our results have gained international recognition.

Looking ahead, much of our collaborative work will persist. New projects are continuously developed, thanks to the fertile ground provided by our partners and previous achievements. Many students and PhD candidates are now part of our partner organizations, contributing to the industry's ongoing restructuring and the search for robust, safe, and efficient operations.

Key researchers involved:

Name	Position
Hans V. Bjelland	Research Director
Ingunn Marie Holmen	Research Manager
Trine Thorvaldsen	Senior Research Scientist
Heidi Moe Føre	Senior Research Scientist
Per Christian Endresen	Research Scientist
Jan Tore Fagertun	Research Manager
Ørjan Selvik	Senior Adviser
Martin Gutsch	Senior Research Scientist
Eivind Lona	Senior Project Manager

3. References to the research

- Thorvaldsen, T., Salomonsen, C., Ranum, S. A., Trædal, P., Misund, A. & Holmen, I. M. (2023). *Prepared for the worst? Emergency preparedness in Norwegian fish farming – Status and further improvements.* Aquaculture, Vol. 577, 739921. https://doi.org/10.1016/j.aquaculture.2023.739921
- Holmen, I. M. (2022). *Safety in Exposed Aquaculture Operations: Strategies and Methods for Reducing Risk*. Doctoral thesis. Norwegian University of Science and Technology, Faculty of Engineering, Department of Marine Technology; 2022. https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/2986347

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4. Details of the impact

Most of the impact related to exposed aquaculture operations, is based in the activities of CRI EXPOSED. The centre was funded from 2015 to 2023 by partners and the Research Council of Norway, and utilized the Centre for Research-based Innovation (CRI) status to cultivate productive, long-term collaboration. The eight-years partnership has fostered joint problem-solving and helped shape a unified direction and vision.

Our approach included joint activities like annual gatherings, thematic workshops, and weekly video meetings. A broad range of stakeholders have been involved, with company representatives, researchers, PhD candidates, students, and other invitees, such as government representatives. This new knowledge and collaboration have increased quality and coherence in the Norwegian research system.

Most of EXPOSED's activities represent a collaborative effort from all research partners - IMR, NTNU, SINTEF Ocean, and SINTEF Digital. For these research groups, the Centre has expanded knowledge, networks, and the extent of research activities and topics. The value of this collaboration has been highlighted during meetings and EXPOSED-themed discussions about the practical challenges faced by fish farmers. This emphasizes the importance of a multidisciplinary approach and close collaboration among research groups and partners. In 2022, NTNU, NTNU Societal Research and SINTEF established a Gemini centre for sustainable aquaculture in order to coordinate these strong research groups.

Several of EXPOSED's research partners have also worked together on several associated projects, such as SFI Smart Maritime, SFI MOVE, SFI Blues, SFI Autoship, SFI Harvest and NTNU AMOS (Centre for Autonomous Marine Operations and Systems). These collaborations have involved research activities, model development, knowledge exchange, and joint publications.

EXPOSED has also collaborated with other NTNU and SINTEF research centres to evaluate the critical factors for innovation in large partnerships and the CRI/SFI system. The goal of this SFI Task Force is to strengthen and enhance the Norwegian innovation ecosystem. They are striving to better understand, measure, and highlight all types of innovations emerging from the SFIs. Their report, due for release in the fall of 2023, aims to shape the research system in the coming years.

Moreover, the research partner NTNU has made structural advancements in their research and educational system. They introduced a minor in aquaculture for technology and engineering

students, now available to all students pursuing a 5-year master's degree at NTNU. As stated on the NTNU webpage, "minor students form an interdisciplinary group from various technology programs, sharing a common interest in Norway's second largest economy - the aquaculture sector. Through a combination of specialized subjects, industry-led meetings, and company visits, students are well prepared to join an industry increasingly focused on technology. The seminar themes are derived from practical knowledge, research, and societal needs:

- Aquaculture as a system and technology
- Fish welfare
- Technology development on biology's terms
- Sustainable aquaculture

The partners of the EXPOSED Centre anticipate a lasting, positive impact stemming from its work. With significant challenges still present and considerable potential for enhanced solutions, the outcomes of EXPOSED are expected to inspire a variety of innovations and further research. In fact, the partners are continually refining their products based on these results.

One of EXPOSED's greatest accomplishments has been the establishment of a robust network comprising various disciplines and organizations. The aquaculture industry's concepts and regulations are currently undergoing substantial transformation. The results of EXPOSED are helping shape these technological and policy advancements.

From a research perspective, the Centre's activities have inspired several new projects. EXPOSED has underscored that exposed and offshore aquaculture represent unique realities, each demanding different approaches and solutions. The EXPOSED partners have developed specialist competence in these areas. EXPOSED has not emphasized on offshore aquaculture as this is still not in operation, but has gained useful knowledge when offshore aquaculture is being planned.

SFI Blues aspires to empower the Norwegian industry to create innovative floating stationary structures. These structures will meet diverse needs and requirements in the renewable energy, aquaculture, and coastal infrastructure sectors. The knowledge and expertise nurtured through EXPOSED play a crucial role in achieving this goal. SFI Blues will further explore research questions about maritime environment and aquaculture technology.

Moreover, infrastructure elements like buoys, fish tags, swimming tunnels, and models, provided by EXPOSED and owned by the partners, will continue to be used in research projects to expand knowledge about fish or aquaculture sites.

Looking ahead, SINTEF Ocean plans to incorporate the research outcomes from EXPOSED into the forthcoming Norwegian Centre for Ocean Technology. This represents the most substantial single investment in maritime research infrastructure in recent Norwegian history.

5. Sources to corroborate the impact

- EXPOSED: Final Report 2015 – 2023 (2023): https://www.sintef.no/globalassets/sintef-ocean/exposed-final-report-2023.pdf
- Overview of media articles about EXPOSED: https://www.sintef.no/prosjekter/2015/exposed-aquaculture/publikasjoner/exposed-i-media/

- Making offshore aquaculture a reality (2023): https://weareaquaculture.com/news/aquaculture/making-offshore-aquaculture-a-reality/35545/
- New techniques to prevent farmed salmon escapes (2022): https://thefishsite.com/articles/new-techniques-to-prevent-farmed-salmon-escapes
- Deep learning may help to prevent salmon escapes in rough seas (2022): https://norwegianscitechnews.com/2022/12/deep-learning-may-help-to-prevent-salmon-escapes-in-rough-seas/#:~:text=The%20more%20precise%20the%20information,excellent%20foundation%20for%20operational%20planning.
- Has studied the vessels operating on fish farms (translated from Norwegian) (2023): https://www.radionordkapp.no/nyheter/22847/har-studert-fartoyene-som-opererer-pa-oppdrettsanlegg/
- Model trials led to stricter requirements for fish farming (translated from Norwegian (2022): https://www.tu.no/artikler/modellforsok-forte-til-strengere-oppdrettskrav/522523
- Technological answers to the minister's requirements (translated from Norwegian) (2022): https://ilaks.no/teknologiske-svar-pa-ministerens-krav/
- Six out of ten aquaculture employees are concerned that their work will affect their health (translated from Norwegian) (2023): https://www.kyst.no/hms-sintef-ocean/seks-av-ti-havbruks-ansatte-er-bekymret-for-at-jobben-skal-ga-ut-over-helsen/1597371

SINTEF Ocean – Case 2

Institution: SINTEF
Administrative unit: SINTEF Ocean, Department of energy and transport and Department of ships and ocean structures
Title of case study: Reduction of greenhouse gas emissions in maritime transport
Period when the underpinning research was undertaken: 2015 - 2023
Period when staff involved in the underpinning research were employed by the submitting institution: 2015 - 2023
Period when the impact occurred: 2015 onwards

1. Summary of the impact

1. More efficient and accurate early-stage assessment of new ship designs,
2. New validated methods to correlated data from real-life conditions with simulation- and experimental data.
3. More accurate predictions of fuel consumptions and emissions from alternative hull, propulsions and power systems configurations and operational profiles.
4. Improved optimization of ship performance versus cost profiles at various profiles and sea states.
5. Increased knowledge on the potential energy savings from new and innovative technologies
6. Improved methods and software tools for cost and fuel optimization on both unit and fleet level.
7. The report ("Sea map to Green Shipping") describing a four-step approach towards zero emission maritime transport.

2. Underpinning research

SINTEF Ocean has together with partners through several research projects, and in the SFI Smart Maritime Centre (https://www.smartmaritime.no/) and Kongsberg University Technology Centre (UTC) Performance in a Seaway (https://www.kongsberg.com/maritime/services/hydrodynamics--collaboration--references/hydrodynamic-research-and-software-development/kongsberg-university-technology-centres-utc/) in particular, developed state-of-the-art knowledge, competence, models, tools and solutions to reduce greenhouse gas emission from maritime transport. This research has provided insight on potential emission reductions from ships and tested out novel technology solutions.

The Smart Maritime research centre was operative from 2015 until 2023, and the Kongsberg University Technology Centres has been operative since 2005.

The results of the research include knowledge and solutions for:

- Improving hull and propeller performance to reduce energy use,
- Improved energy systems,
- Studies of alternative fuels, such as biofuel, hydrogen and ammonia,
- Development of hybrid energy systems and multifuel engines,
- Energy saving devices and wind assisted propulsion,
- Combining and integrating models for power, hydrodynamics, energy saving devices, etc. with weather information and operational profiles, to create a ship performance simulator and decision support systems,

- Feasibility and system level studies to compare alternative strategies, understand implications and dependencies, and showcase GHG reduction potential.

Key researchers involved:

Name	Position
Elizabeth Lindstad	Chief Scientist
Torstein Bø	Senior Software Developer
Jørgen Bremnes Nielsen	Research Scientist
Endre Sandvik	Senior Research Scientist
Benjamin Lagemann	Research Scientist
Agathe Rialland	Research Scientist
Anders Valland	Research Manager
Gunnar Malm Gamlem	Project Manager
Jon Dæhlen	Senior Software Developer
Kourosh Koushan	Special Advisor
Anders Alterskjær	Research Manager
Thomas Sauder	Senior Research Scientist
Martin Gutsch	Senior Research Scientist
Anders Östman	Senior Research Scientist
Kevin Koosup Yum	Senior Research Scientist
Edvard Ringen	Senior Software Developer
Dariusz Fathi	Research Director
Trond Johnsen	Centre Director Smart Maritime

3. References to the research

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- Esmailian, Ehsan; Steen, Sverre; Koushan, Kourosh. Ship design for real sea states under uncertainty. Ocean Engineering 2022 ;Volume 266.(5) p.
- Sauder, Thomas Michel; Alterskjær, Sverre Anders. Hydrodynamic testing of wind-assisted cargo ships using a cyber–physical method. Ocean Engineering 2021 ;Volume 243. p.
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- Shakeri, Nastaran; Zadeh, Mehdi; Nielsen, Jørgen Bremnes. Hydrogen Fuel Cells for Ship Electric Propulsion: Moving Toward Greener Ships. IEEE Electrification Magazine 2020 ;Volum 8.(2) s. 27-43
- Bø, T. I., Vaktskjold, E., Pedersen, E. & Mo, O. 2019. Model Predictive Control of Marine Power Plants with Gas Engines and Battery. IEEE Access, 7, 15706-15721.
- Annual reports and final report of SFI Smart Maritime; https://www.smartmaritime.no/main/shortcuts/about-smart-maritime/ and https://prosjektbanken.forskningsradet.no/en/project/FORISS/237917?Kilde=FORISS&distribution=Ar&chart=bar&calcType=funding&Sprak=no&sortBy=date&sortOrder=desc&resultCount=30&offset=1080&TemaEmne.1=Digitalisering+og+bruk+av+IKT

4. Details of the impact

We have chosen to divide the research leading up to the impact case "Reduction of greenhouse gas emissions in maritime transport", into four main topics. These four topics loosely follows the divisions used in organizing and reporting the results from the SFI Smart Maritime centre. For each research topic the main results are presented, and to which of the six impacts the research results are relevant. As a synthesis of the findings from the research within SFI Smart maritime, as well as adjoining projects, the report " Sea map to Green Shipping" describing a four-step approach towards zero emission maritime transport has been produced. A summary of the research on green shipping to inspire and advise ship owners regulators and maritime stakeholders.

Main research topic: Hydrodynamics and propulsion
Research results:

- Methods and technologies to reduce hull friction by design and optimization of surface structures.
- Modeling of hydrodynamics for energy saving measures and devices.
- Knowledge and methods to estimate added resistance and propulsor performance in waves and integration into design software (VERES3D)
- Development of models to calculate contributions from wind assisted propulsion and integration into design software.

Relevant to impact:

- More accurate predictions of fuel consumptions and emissions from alternative hull, propulsions and power systems configurations and operational profiles.
- Improved optimization of ship performance versus cost at various operational profiles and sea states

Main research topic: Power systems and fuel
Research results:

- Knowledge and methods to model and simulate hybrid power systems for ships.
- A model for optimal ship lifetime fuel and power system selection
- Well to wake analysis of energy use and carbon emission for alternative fuels, providing important insight for decarbonization pathways.

Relevant to impact:

- Improved methods and software tools for cost and fuel optimization on both unit and fleet level
- More accurate predictions of fuel consumptions and emissions from alterative hull, propulsions and power systems configurations and operational profiles

Main research topic: Simulation platform and Ship System Integration
Research results:

- Developed a hybrid power system simulator, developed software for optimization of ship routing, included models for wind-assisted propulsion and active route and speed decisions for realistic evaluation of unproven technology.
- Software for virtual testing of ship design solutions, providing insight that improve early-stage design decisions.
- Development of a system-oriented analysis platform with simulation tools for hull and propeller optimization and power systems.

Relevant to impact:

- More efficient and accurate early-stage assessment of new ship designs
- New validated methods to correlated data from real-life conditions with simulation- and experimental data
- Improved optimization of ship performance versus cost profiles at various profiles and sea states.
- Improved methods and software tools for cost and fuel optimization on both unit and fleet level.

Main research topic: Feasibility studies

- Investigation of under what conditions LNG can serve as a transition fuel in the decarbonization of maritime transport.
- Assessment of alternative fuel pathways considering GHG emission, energy usage and cost, in a Well-to-wake perspective
- Investigated different decarbonization scenarios demonstrating the importance of adopting a broad view on technology and strategy development to understand the potential of distinct GHG reduction measures and how distinct technologies and measures work together.

Relevant to impact:

- The report ("Sea map to Green Shipping") describing a four-step approach towards zero emission maritime transport.

5. Sources to corroborate the impact

- Annual reports and final reports of SFI Smart Maritime; https://www.smartmaritime.no/main/shortcuts/about-smart-maritime/ and https://prosjektbanken.forskningsradet.no/en/project/FORISS/237917?Kilde=FORISS&distribution=Ar&chart=bar&calcType=funding&Sprak=no&sortBy=date&sortOrder=desc&resultCount=30&offset=1080&TemaEmne.1=Digitalisering+og+bruk+av+IKT
- Havyard Design & Solutions used the simulation software GYMIR, developed through SFI Smart Maritime, to optimize their design for the public bid on the coastal route between Bergen and Kirkenes; https://www.tu.no/artikler/oppdraget-et-skip-som-gar-bergen-kirkenes-med-lavest-mulig-energiforbruk-da-ma-det-tusenvis-av-simuleringer-til/483031 (In Norwegian)
- A newly established project based on these results to design and build a low emission coastal cruise vessel https://www.hurtigruten.com/en-us/about-us/sustainability/sea-zero
- Sea map to Green Shipping (to be published soon)
- Development and verification of ship concepts for cost efficient and environmentally friendly naval defense vessels. https://www.skipsrevyen.no/fremtidens-skipskonsept-for-sjforsvaret/102869
- Autonomous and fully electric container vessel, YARA Birkeland. https://www.skipsrevyen.no/aktuelt/pa-tur-med-havets-tesla/250814

SINTEF Ocean – Case 3

Institution: SINTEF
Administrative unit: SINTEF Ocean
Title of case study: Offshore Wind
Period when the underpinning research was undertaken: 2012-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2012-2022
Period when the impact occurred: 2013-2022

1. Summary of the impact

SINTEF Ocean has developed competence, tools and laboratories which are applied in development and testing of new concepts for floating offshore wind. The research community at SINTEF Ocean has been involved in the majority of the floating wind concepts presently installed or which are under commissioning. Knowledge, software, laboratories and methods from SINTEF Ocean have been instrumental for realization of floating offshore wind and is therefore strongly contributing to the green transition with more renewable energy production and green jobs.

2. Underpinning research

Floating offshore wind turbines are exposed to loads from wind, waves and ocean current. Numerical simulation and scaled experiments are vital tools for assessing the performance during the design phase. SINTEF Ocean has developed tools and methods for simulation and testing of offshore wind turbines**.** The research underpinning the present impact case study follows two intertwined development paths:

1. Development of simulation software for global analysis of fixed and floating offshore wind turbines, in particular the simulation tool **SIMA**.
2. Development of experimental methods for scaled hydrodynamic laboratory testing of fixed and floating offshore wind turbines, in particular **Real time hybrid testing.**

Both relies on a strong marine technological background in offshore oil and gas developed over the past 40 years.

SIMA is an aero-hydro-servo-elastic simulation tool for global analysis of offshore wind turbines. It is fully coupled and applies non-linear analysis in time domain with the finite element method. SIMA can be coupled to state-of the-art hydrodynamic tools such as Wadam, Wasim and WAMIT, and to numerical wave tanks for high-fidelity calculation of wave kinematics. It can also be used together with numerical tools for local analysis of for instance hull or power cable. SIMA has been developed since 2008 and distributed commercially since 2013. SIMA is distributed world-wide by DNV Digital Solutions, as part of Sesam – a software suite for hydrodynamic and structural analysis of renewable, offshore and maritime structures. SIMA is intellectual property of SINTEF Ocean.

Real time hybrid testing is cyber-physical method where the physical experiment (in a wave tank) interacts in real-time with a numerical simulation of the wind and turbine loads. The method enables representation of wave, current and wind loads on the floating wind turbine with high accuracy, and hereby obtaining the complete picture of its dynamic response. This method solves the notorious Froude-Reynolds scaling mismatch issues. Froude scaling is adequate to scale down waves while Reynolds scaling is adequate for wind; but both can't be achieved at the same time. As wave and wind loads are equally important for floating wind turbines, real time hybrid testing is the only way to obtain the full picture of the problem in experiments. Additional benefits of the

method are controlled wind field, reduced cost for model testing and increased flexibility in the test conditions. Most of the floating wind turbines producing electricity today, or the ones which are under development, have been undergoing cyber-physical tests at SINTEF Ocean.

The development of methods, tools and software for offshore wind turbines has taken place in several large collaborative research projects, the main ones are listed below:

- FME NOWITECH - Norwegian Research Centre for Offshore Wind Technology (2009-2017). https://prosjektbanken.forskningsradet.no/en/project/FORISS/193823
- Software development projects funded by Equinor (2012-2022).
- Lifes50+ (2015-2019) https://lifes50plus.eu/
- HYBRID KPN (2016-2020) https://prosjektbanken.forskningsradet.no/project/FORISS/254845
- WINDMOOR (2019-2023) https://prosjektbanken.forskningsradet.no/en/project/FORISS/294573
- MooringSense (2019-2022) https://www.mooringsense.eu/
- ImproveFlow (2021-2024) https://prosjektbanken.forskningsradet.no/project/FORISS/321549
- Cyberlab (2022-2025) https://prosjektbanken.forskningsradet.no/project/FORISS/326654

Key researchers involved:

Name	**Position**
Thomas Sauder	Senior Research Scientist
Maxime Thys	Senior Research Scientist/Research Manager
Erin E. Bachynski-Polić	Research Scientist (2014-2016)
Petter Andreas Berthelsen	Senior Research Scientist/Research Manager
Lars Ove Sæther	Senior Software Engineer
Øyvind Berg Magnussen	Senior Software Engineer
Carlos Eduardo Silva de Souza	Research Scientist (2019-)
Harald Ormberg	Senior Research Scientist
Elizabeth Passano	Senior Research Scientist
Lene Vien Eliassen	Senior Research Scientist (2017-)
Marit Kvittem	Senior Research Scientist (2017-)
Madjid Karimirad	Research Scientist (2014-2017)
Ivar Fylling	Senior Research Scientist (-2015)
Nuno Fonseca	Chief Scientist
Ole Andreas Hermundstad	Senior Research Scientist

3. References to the research

- Nuno Fonseca, Carlos Eduardo Silva de Souza, Petter Andreas Berthelsen (2022). *Prediction of Heave and Pitch Low Frequency Wave Forces and Motions of a Semi-Submersible Floating Wind Turbine and Comparison with Model Test Data*. ASME 2022 4th International Offshore Wind Technical Conference. https://doi.org/10.1115/IOWTC2022-95009
- Maxime Thys, Valentin Chabaud, Thomas Sauder, Lene Eliassen, Lars O. Sæther, Øyvind B. Magnussen (2018). *Real-Time Hybrid Model Testing of a Semi-Submersible 10MW Floating Wind Turbine and Advances in the Test Method*. ASME 2018 1st International Offshore Wind Technical Conference. https://doi.org/10.1115/IOWTC2018-1081

- Thomas Sauder, Valentin Chabaud, Maxime Thys, Erin E. Bachynski, Lars Ove Sæther (2016). *Real-Time Hybrid Model Testing of a Braceless Semi-Submersible Wind Turbine: Part I — The Hybrid Approach*. ASME 2016 35th International Conference on Ocean, Offshore and Arctic Engineering. https://doi.org/10.1115/OMAE2016-54435
- Erin E. Bachynski, Maxime Thys, Thomas Sauder, Valentin Chabaud, Lars Ove Sæther (2016). *Real-Time Hybrid Model Testing of a Braceless Semi-Submersible Wind Turbine: Part II — Experimental Results*. ASME 2016 35th International Conference on Ocean, Offshore and Arctic Engineering. https://doi.org/10.1115/OMAE2016-54437
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- Harald Ormberg, Erin Bachynski (2012). *Global analysis of floating wind turbines: code development, model sensitivity and benchmark study*. Proc Int Offshore Polar Eng Conf. 2012;4:366-373.

4. Details of the impact

SIMA:
The development of SIMA started in 2008 and offshore wind functionality has been developed and implemented continuously since then. The first phase of the development was funded through joint industry projects, bilateral industry projects and FME Nowitech. Since 2013, SIMA has been distributed commercial by DNV as part of the Sesam software suite, and per 2022 SIMA generates around 8-10 MNOK in yearly license revenues for SINTEF and corresponding revenues for DNV. DNV has a global presence and a particularly strong position in Europe and Asia. There are now around 70 companies using SIMA worldwide. Some examples of companies benefiting from use of SIMA are given below.

Equinor is large energy company with high focus on floating offshore wind. Through Hywind Demo, Hywind Scotland and Hywind Tampen, Equinor has proven to be a forerunner within floating offshore wind. Equinor has funded large parts of the development of SIMA and has been using SIMA actively for both research, design and operation of floating wind turbines throughout the whole period and for all of Equinor's installed and planned floating wind turbines. One example is described in Skaare et al (2015) https://doi.org/10.1002/we.1750, where simulations from SIMA is compared with full scale measurements from the Hywind Demo offshore wind turbine. **COWI** is an engineering company and designer of foundations for offshore wind. SIMA, together other simulation software within the Sesam suite, has enabled COWI to have a leading position in the market for offshore wind foundation design, and to keep up with the latest market demands. **Taisei** is a Japanese EPCI contractor which has used SIMA and Sesam design for floating wind turbines. Taisei has gained significant time reduction in analysis and thereby improved their design process. **Saitec Offshore Technologies** has been using SIMA and Sesam since 2014 to design their innovative floating wind foundation SATH. Their concept is now in the prototype phase with several pre-commercial developments underway.

Real-time hybrid testing:
Several floating wind concepts have been tested using real-time hybrid testing since 2018, both as part of multi-partner research projects and in commercial projects. In 2018, two floating foundations were tested and verified during the project Lifes50+, funded by the European Commission. The Norwegian engineering company **Dr Techn Olav Olsen** developed the OO-Star which was later sold to the French company Bouygues Travaux Publics, and it is also scheduled for full-scale testing at Metcentre, Norway. The other foundation which was tested in Lifes 50+ was

developed by the Spanish company **Nautilus Floating Solutions**. The above-mentioned concept SATH, developed by **Saitec Offshore Technologies** was tested as part of the MooringSense project, funded by the European Commission, and in a commercial project, both in 2021. WINDMOOR was a research project funded by the Research Council of Norway, where the INO WINDMOOR floating wind turbine was developed and tested in 2020. The INO WINDMOOR was further developed by **Inocean** and **Equinor** and later tested for the Firefly offshore wind farm in Korea in 2023. Equinor has also tested a similar foundation called Wind Semi in 2020 and 2021, as well as Hywind Tampen in 2021. All the latter tests were commercial projects. The French company **Naval Energies** tested a semi-submersible floating wind turbine in 2019, and the concept was later sold til Sofresid Engineering. Lately, also Norwegian companies **Fred. Olsen** and **Ocean Ventus** have tested their designs of floating wind turbines using real-time hybrid testing in SINTEF's Ocean Basin. SINTEF Ocean has also assisted the American design company Principle Power when they performed real-time hybrid testing in the laboratory of the US Navy in 2022.

5. Sources to corroborate the impact

Model testing offshore wind turbines for various clients:

- Floating Offshore Wind Farm: Will it withstand typhoons? (2023) https://fireflywind.com/n-230331/
- SINTEF Ocean assists Principle Power when performing tests at the US Navy (2022) https://blog.sintef.com/sintefocean/sintef-ocean-assists-principle-power-when-performing-tests-at-the-us-navy/
- Nautilus floating concept braves tank trials (2019) https://www.rechargenews.com/wind/nautilus-floating-concept-braves-tank-trials/2-1-315904
- Testing tomorrow's offshore wind technology (2018) https://www.youtube.com/watch?v=l3gQeD_rVe8
- OO-Star WF floating wind concept advances with tank tests (2017) https://www.rechargenews.com/wind/oo-star-wf-floating-wind-concept-advances-with-tank-tests/2-1-213602
- New and more effective model test (2015) https://www.youtube.com/watch?v=jzRDKdyFCTI

Application of SIMA for offshore wind by various clients:

- Equinor: Simulations of Hywind Demo with SIMA:
  Bjørn Skaare, Finn Gunnar Nielsen, Tor David Hanson, Rune Yttervik, Ole Havmøller, Arne Rekdal (2015). *Analysis of measurements and simulations from the Hywind Demo floating wind turbine*. Wind Energy 2015; 18:1105–1122. https://doi.org/10.1002/we.1750
- COWI uses combined power of Bladed and Sesam https://www.dnv.com/cases/cowi-uses-combined-power-of-bladed-and-sesam-220355
- Taisei uses DNV software solutions for offshore wind projects https://www.dnv.com/cases/taisei-uses-dnv-software-solutions-for-offshore-wind-projects-234575
- Saitec Offshore Technologies on new path with Sesam https://www.dnv.com/cases/saitec-offshore-technologies-110357

[University of Agder_Department of Information systems [Case 1]

Institution: UiA
Administrative unit: Department of Information Systems
Title of case study: Strengthening resilience management through information systems
Period when the underpinning research was undertaken: 2015-2023
Period when staff involved in the underpinning research were employed by the submitting institution: 2015 – today
Period when the impact occurred: 2015 - today

1. Summary of the impact (indicative maximum 100 words)

The case study describes the impact of collaborative research with emergency management stakeholders at regional, national and international level on practice related to use of information systems for supporting resilience management.

The research has provided knowledge, methods and tools for systemic risk management, exercise planning and evaluation, and situational awareness related to different crisis scenarios, thus contributing to strengthening societal resilience through improving practice in crisis preparedness and management.

2. Underpinning research (indicative maximum 500 words)

CIEM's research focuses on contributing to improved societal resilience through innovative use of technology for crisis preparedness and response. The centre works closely with stakeholders involved in crisis management at the regional and national level in Norway. The research findings have been developed based on qualitative interviews and workshops with emergency management professionals, and observation and participation in emergency exercises and field trials. The research in CIEM is interdisciplinary, combining emergency management, information systems, computer science, social science and engineering.

The underpinning research was mainly carried out in the following three research projects:

SMR - Smart Mature Resilience (2015-2018), EU Horizon 2020 project, with CIEM as scientific coordinator. CIEM lead participants were Gonzalez, Radianti and Majchrzak.
In the SMR project, researchers and emergency management professionals from seven European cities together developed a European Emergency Management Guideline, for enhancing urban communities' capacity to resist, absorb and recover from the hazardous effects of climate change. A set of practical tools was piloted in a core group of cities and shared with a wider group of cities, strengthening the nexus of Europe's resilient cities. The project has been acclaimed for an exceptionally successful implementation.

INSITU - Sharing Incident and Threat Information for Common Situational Understanding (2019-2022), project funded by the SAMRISK programme in the Research Council of Norway. Project manager: Munkvold. Other key participants from CIEM: Radianti, Steen-Tveit, Gjøsæter.
The INSITU project addressed challenges in effectively sharing information among different organisations involved in crisis response, for developing a shared situational understanding. The project developed knowledge and solutions for harmonized terminology, use of digital maps, and procedures for information sharing.

SPRM - Systemic Pandemic Risk Management (2020-2023), project funded by the Research Council of Norway. CIEM lead participants: Gonzalez, Radianti, Gjøsæter.
The SPRM project has developed further the methods for systemic analysis and management of interdependent risks that were first used in the Smart Mature Resilience project (see above). The methods were used to evaluate the Covid-19 response in the Agder county in Southern Norway, with the participation of a broad focus group from Kristiansand municipality, Hospital of Southern Norway and other relevant stakeholders. The evaluation has provided insights for more effective prevention and management of new Covid waves and future pandemics, and also serves as the basis for continued use in other areas related to crisis management and disaster risk reduction (see point 4).

Key researchers involved in one or more of the three mentioned projects:

Bjørn Erik Munkvold, professor, Director of CIEM
Jose J. Gonzalez, professor (emeritus from 2019)
Jaziar Radianti, associate professor, full professor from 2022
Tim A. Majchrzak, professor
Kristine Steen-Tveit, PhD research fellow/researcher (2018-2022), postdoc (from December 2022)
Terje Gjøsæter, assistant professor (joined UiA/CIEM in August 2020)

3. References to the research (indicative maximum of six references)

1. Marana et al. "Towards a resilience management guideline — Cities as a starting point for societal resilience". 2019, Sustainable Cities and Society, vol. 48, 101531, https://doi.org/10.1016/j.scs.2019.101531.
2. Munkvold, B.E., Opach, T., Radianti, J., Rød, J.K., Snaprud, M., Grottenberg, L.O., Pilemalm, S., Bunker, D., Majchrzak, T.A., Hagen, D.A., Moen, E. and Steen-Tveit, K. "Project report: Requirements specification". 2020, SAMRISK project INSITU. University of Agder, Norway. ISBN 978-82-7117-981-6. https://uia.brage.unit.no/uia-xmlui/handle/11250/2658074
3. Steen-Tveit, K., Radianti, J. and Munkvold, B.E. "SMS-based real-time data collection for evaluation of situational awareness and common operational picture: lessons learned from a field exercise. 2020, *Proceedings of the 17th International Conference on Information Systems for Crisis Response and Management (ISCRAM 2020)*, pp. 276-294. http://idl.iscram.org/files/kristinesteen-tveit/2020/2228_KristineSteen-Tveit_etal2020.pdf
4. Steen-Tveit, K. and Munkvold, B.E. "From common operational picture to common situational understanding: An analysis based on practitioner perspectives". 2021, *Safety Science*, Vol. 142, Article 105381, https://doi.org/10.1016/j.ssci.2021.105381.
5. Gonzalez, J. et al. "Elicitation, analysis and mitigation of systemic pandemic risks". *Proceedings of the 18th International Conference on Information Systems for Crisis Response and Management (ISCRAM 2021)*, https://idl.iscram.org/files/josejgonzalez/2021/2357_JoseJ.Gonzalez_etal2021.pdf
6. Abildsnes, E., Paulsen, S. and Gonzalez, J.J. "Improving resilience against a pandemic: A novel technology for strategy development with practitioners and decision-makers". 2023, *Proceedings of the 20th Global Conference on Information Systems for Crisis Response and Management (ISCRAM 2023)*, https://idl.iscram.org/files/abildsnes/2023/2580_Abildsnes_etal2023.pdf

4. Details of the impact (indicative maximum 750 words)

In all three projects mentioned in section 2, workshops and focus group meetings with emergency management stakeholders were a key mechanism for co-creation and dissemination of knowledge.

In the SMR project, besides the seven core European cities participating as partners in the project, the workshops included additional cities and city networks as well as research organizations involved in similar projects, and consultancies involved in standardisation. The project resulted in an European Resilience Management Guideline and a set of tools to operationalize this: 1) a Resilience Maturity Model defining the trajectory of an entity through measurable resilience levels; 2) a Systemic Risk Assessment Questionnaire that, beyond assessing the entity's risk, determines its resilience maturity level; 3) a portfolio of Resilience Building Policies that enable the entity's progression towards higher maturity levels; 4) a System Dynamics Model allowing to diagnose, monitor and explore the entity's resilience trajectory as determined by resilience building policies, and, 5) a Resilience Engagement and Communication Tool to integrate the wider public in community resilience, including public-private cooperation. More information on the project participants and results are available from the project website: https://smr-project.eu/

Through involvement of the German standardization institute DIN as project partner, the project developed three CEN Workshop Agreements (CWA) (CEN is the European Committee for Standardization) based on the project outputs. The CEN Workshop Agreement Series on City Resilience Development intends to support cities in building resilience to various kinds of threats, and consists of the following CWAs:

CWA 17300 City Resilience Development - Operational Guidance
CWA 17301 City Resilience Development - Maturity Model
CWA 17302 City Resilience Development - Information Portal

In 2019, the SMR project was presented with the inaugural CEN/CENELEC Standards + Innovation Award that is given to European research/innovation projects that successfully contribute to standardization, see ref a). For more information on the work with standardization in SMR, see ref. b), including statements from emergency managers in Italy, Denmark and Norway. In 2019, Professor Gonzalez received the King'd Medal of Merit for his efforts in public safety and emergency preparedness in Norway and in Europe, and specifically focusing on the SMR project (ref. c).

The INSITU project included a reference group of more than 20 organisations from different societal sectors, including the Ministry of Justice and Public Security, the Norwegian Directorate for Civil Protection, other national directorates and agencies, emergency managers at the county and municipal levels, providers of critical infrastructure (e.g., energy company, public road administration), and volunteer organisations.

The requirements analysis conducted in the first phase of the project resulted in increased understanding of the information needs of different emergency responders involved in complex emergency events (see article reference 2 above). The main focus has been on crisis scenarios caused by extreme weather, such as forest fire and flooding. Based on analysis of existing practices related to establishing COPs by use of digital map systems, the project has developed new knowledge resources in the form of an archive of harmonised emergency map symbols and an inventory of map-functions. As reported in scientific articles from the project, the results have also provided an increased understanding of the required process for advancing from a COP to a common situational understanding in inter-agency operations (e.g., article reference 4 above). Further, the project has contributed to method development for planning and evaluation of exercises, including novel methods for analysing audio logs and using SMS for near real-time analysis of perceived situational understanding in emergency exercises (see article reference 3

above). The project has also developed software tools that have been tested and validated in exercises and workshops involving different user groups, with one of these tools (SQUARE) currently being considered for commercialization.

A main activity in the project was a digital tabletop exercise conducted in 2021, with over 70 participants from 20 organisations (mainly from the project reference group). The exercise involved a novel combination of a shared digital map and audio communication through the Norwegian critical communication network (Nødnett), for analysing how access to this shared platform could improve practice related to information sharing and situational reports from the incident command, through the regional coordination at the County governor, and to the Norwegian Directorate for Civil Protection and the Ministry of Justice and Public Security. Prior to the exercise, extensive online tutorials and exercise material were made available for the participants. The project partners from NTNU, Department of Geography, were responsible for the training material related to the map system.

The post-exercise evaluation documented a successful learning outcome of the exercise, both from the participants' internal evaluations as presented by DSB, the County Governor of Agder, and Agder Energi (now Å Energi) and from the group interviews conducted by the INSITU project team. Especially, they emphasized new insight in the value of shared map services for common situational understanding. For further detail on the INSITU exercise and the evaluation results, we refer to the evaluation report (in Norwegian) listed as reference e) below.

Apart from the scientific articles, results from the project were disseminated in invited presentations at practitioner conferences, seminars and professional journals, see refs f), g) and h). The Kristiansand conference (Kristiansandskonferansen) is the annual regional conference for first responders and emergency management professionals from public and private sector, gathering approximately 200 participants each year. The CIM conference is the annual user forum for the main crisis management system in use in Norway (until 2023), hosted by the company F24. At the time of the presentation, CIM had more than 900 user organisations in public and private sector. Both conferences were conducted online due to the pandemics.

The SPRM project followed the same approach as the SMR project, conducting a series of workshops with stakeholders representing critical societal functions (hospital management, municipal emergency manager, home care management, police, transport operators (bus, lorries, ferry, airport), etc.) to elicit and analyze systemic pandemic risks related to the Covid-19 pandemic and develop the most effective mitigation strategies for these. Through these workshops the stakeholders built experience with the method applied for the systemic risk analysis and the *Strategyfinde*r tool used for modelling this. In addition to the scientific papers (see for example articles 5 and 6 reference above, developed together with user representatives), the project was also featured as a case study in a recent report from the IBM Center for The Business of Government (ref. i) below).

The beneficiaries of these three projects thus include a broad range of stakeholders involved in crisis preparedness and management, at the tactical, operational and strategic level. The nature of the impact can be summarized as:

- Development of innovative methods and related tool support for systemic risk management and resilience related to different scenarios
- Increased competence on mutual needs for information sharing among organizations involved in joint emergency management operations
- Increased understanding of the benefit of using shared digital for situational reports and developing common situational understanding, and related requirements for procedural support
- Documented benefits of using map-based support for systematic evaluation from emergency exercises and real events

As evidence and indicators of the impact, the following can be listed:

- Contribution to European resilience management, as documented from the SMR project.

- CIEM researchers being invited as advisors for regional emergency management exercises by 110 Øst (the fire alarm central in Eastern Norway) and the regional search and rescue exercise in Agder county (LRS Agder), both with approximately 200 participants from different first responder agencies and emergency management stakeholders. In these exercises, CIEM contributed to defining the exercise goals and planning and conducting the exercise evaluation. The Agder police has also requested the assistance from CIEM to be included as a resource in the further LRS exercises.

- Results from the INSITU project exercise being the basis for further development of digital map services from the Directorate for civil protection (DSB), as documented in the evaluation report (ref. e)).

- Kristiansand municipality adopting the systemic risk methodology for continued use in other areas related to crisis management and disaster risk reduction, including cyber incidents, problems with energy supply, surge of asylum seekers from Ukraine as consequence of the Russian invasion, and cooperation between the police, the municipality and the Hospital of Southern Norway concerning potential risks to civil defence (see article ref. 6 in section 3).

5. Sources to corroborate the impact (indicative maximum of ten references)

a) https://www.standardsplusinnovation.eu/smrproject
b) Standardization for City Resilience. https://smr-project.eu/standards/
c) https://www.uia.no/en/news/uia-professor-jose-julio-gonzalez-awarded-the-king-s-medal-of-merit
d) Invited articles on the INSITU project results and continued activities in the Sikkerhet (Safety) magazine issued by the Norwegian Industrial Safety Organisation (NSO), Issue 1, 2023, p. 64-71. https://dittmagasin.no/sikkerhet/utgivelser/sikkerhet_01_2023#stotte-for-effektivt-samvirke-ved-storre-hendelser
e) Munkvold, B.E., Gjøsæter, T., Hagen, D.A, Opach, T., Pilemalm, S., Radianti, J., Rustenberg, K., Rød, J.K., Snaprud, M., Steen-Tveit, K. Evaluering av INSITU skogbrannøvelse. Prosjektrapport, SAMRISK-prosjekt INSITU, Universitetet i Agder, Norge. ISBN 978-82-8427-050-0, 2021.
f) Steen-Tveit, K. «Øvelser i samvirke – det enkleste er ofte det beste?». *Politiforum*, published 22.03.2021. Professional journal for the Norwegian police. https://www.politiforum.no/fagartikkel-samvirke-ovelse/ovelser-i-samvirke---det-enkleste-er-ofte-det-beste/212048
g) Rustenberg, K. and Munkvold, B.E. (2022). Et godt samvirke kan kreve at vi må ha tillit til dem vi ikke kjenner. *Ambulanseforum*, published 24.06.2022. Professional journal for prehospital acute medicine.
h) Munkvold, B.E. Presentations of the INSITU project at Kristiansandskonferansen (20.04.21) and the CIM user conference (28.09.2021) https://youtu.be/CCatzt5jV1k.
i) Eden, C. and Gonzalez, J.J. "CASE #2: Understanding and Managing Pandemic-Related Risks to the Norwegian Health and Social Care System Due to the COVID-19 Pandemic". *In Addressing Complex and Cross-Boundary Challenges in Government: The Value of Strategy Mapping*, The IBM Center for The Business of Government, 2023.

[University of Agder_Department of information systems] [case 2]

Institution: UiA
Administrative unit: Department of Information Systems
Title of case study: Digital transformation of education
Period when the underpinning research was undertaken: 2017-
Period when staff involved in the underpinning research were employed by the submitting institution: 2018-
Period when the impact occurred: 2018-2022 and beyond

1. Summary of the impact (indicative maximum 100 words)

Digitalisation in, and of education has been on the research agenda for years, and is one of the research areas CeDiT cover. At CeDiT, researchers have been involved in several R&D projects that address various perspectives on how digital technologies impact education, spanning from compulsory education, higher education, to areas of lifelong learning. Moreover, with a certain eye to the Nordic countries, interdisciplinary teams of researchers from CeDiT have highlighted how digital technoloiges infuses knowledge, academic work, as well as teaching and learning. Here we present one single case study that illuminates some of this complexity, and that demonstrates various types of impact.

The case study involves a school owner, its schools, and a group of researchers from various of disciplines studying the implementation of 1:1 coverage of digital devices in all schools over a period of six years. In Norway, the study was the first of its kind that addressed digital transformations in schools with 1:1 coverage. Being the first study of its kind led to raised awareness from fellow researchers, journalists, and policymakers, in meetings, seminars and conferences.

2. Underpinning research (indicative maximum 500 words)

The research ambition was to develop new knowledge of how to foster professional development among schools, teachers, and students in these new digitalised educational contexts, and how such efforts have led to educational and pedagogical change over time. See more on the details of the impact in section 4. We asked the following research questions: How does the school district support the development of teachers' professional digital competence? What are the roles of school leaders and information and communications technology coordinators? And: How do teachers perceive the 1:1 digital device coverage in terms of pedagogical change? Key findings suggest that over the years, the school district's central administration moved away from a 'one-size-fits-all' or top-down approach towards a more closely adapted (bottom-up) approach centred on individual schools' needs. Moreover, during the years of implementation, school leaders changed their perceptions of their role as facilitators of pedagogical change within their own schools. They became increasingly aware of their responsibility to facilitate the professional development of teachers' digital competence.

The study has provided new insight into educational development work in schools with 1:1 coverage. An interdisciplinary R&D team has carried out the R&D work, which includes qualitative methods such as interviews and participant observation in meetings and gatherings, as well as document analysis. In addition, a pre- and post-surveys were carried out for teachers in the municipality. The R&D team has also included master students who have written their own

master's theses based on the project, and two student teachers have been engaged as research assistants.

3. References to the research (indicative maximum of six references)

Tømte, C. E., Pedersen, C., Vennerød-Diesen, F. F., & Daus, S. (2023). Early and late adopter effects between schools in a one-to-one computer initiative. *Computers & Education*, *207*, 104927. https://doi.org/10.1016/j.compedu.2023.104927

Tømte, C. E., & Smedsrud, J. H. Governance and digital transformation in schools with 1: 1 tablet coverage. In *Frontiers in Education* (Vol. 8, p. 1164856). Frontiers. https://doi.org/10.3389/feduc.2023.1164856

Wollscheid, S., Tømte, C. E., Flittig-Aardalen, H., Vaagland, K., & Vennerød-Diesen, F. (2021). A balancing act–Perceptions of how teachers in Norwegian and mathematics combine digital and analogue devices. *Nordic Journal of Digital Literacy*, (3–4), 102–114. https://doi.org/10.18261/issn.1891-943x-2021-03-04-02

Tømte, C. E., Bugge, M. M., Wollscheid, S., & Vennerød-Diesen, F. F. (2020). Ready to go? Schools' preparedness for teaching and learning within a one-to-one program. In *Responsible Design, Implementation and Use of Information and Communication Technology: 19th IFIP WG 6.11 Conference on e-Business, e-Services, and e-Society, I3E 2020, Skukuza, South Africa, April 6–8, 2020, Proceedings, Part I 19* (pp. 569-580). Springer International Publishing.https://doi.org/10.1007/978-3-030-44999-5_47

4. Details of the impact (indicative maximum 750 words)

Digitalisation in education is highly debated, and there are many anecdotals around what works and does not work in terms of teaching and learning. While such debates are often polarized, with proponents and opponents to digital technologies, researchers play a crucial role in nuancing the picture, with providing research informed evidences. Researchers from CeDiT have been active in such public debates, in writing chronicles and opinion pieces, and by particapting in panels and seminars where topics on digitlaisation and education are discussed. This way our research has been disseminated to various audiences, including policymakers and practitionners, suchs as school leaders, teachers, and parents, to mention a few. Moreover, resarchers in CeDit participate in a current informal dialogue within teacher educators interested in digitalisation and education, from many higher education institutions across Norway and beyond. Here a key issue is on how to promote, and foster professional digital competence for student teachers and in-service teachers.

As for the researchproject within Asker municipality, school owners have to some extent followed the actual principles for implementation of 1:1 coverage, and national authorities have looked to the model when designing a new national strategy for digitalisation in compulsory education.

The study has been presented at NKUL (national conference for teachers professional development) in 2022 and 2023, as a guest lecture for school leaders and teachers in further education courses at UiA (2021, 2022), by researchers for teachers in a gathering at UiO (2023), at the national school leaders' conference (2021), in Udir's round table conference for researchers (2021) and through the project's own final seminar (2023), to name a few.

Network meetings have been held with other municipalities and projects. There have been several network gatherings with researchers at University of South-East Norway, USN, and with the participation of school owners from their associated municipalities, Notodden, Kongsberg and Larvik. Asker has also close collaboration with their neighbour municipality Bærum, and with the Stavanger municipality, in addition to some collaboration with advisors and projects in Nordre Follo and Oslo municipality.

5. Sources to corroborate the impact (indicative maximum of ten references)

The first three years of the research project with Asker municipality included two dissemination reports to stakeholders, one mid term report, and one final report, both in Norwegian language. Here resarchers present findings and elaborate on their implications.

Tømte, C., Wollscheid, S., Bugge, M., & Vennerød-Diesen, F. F. (2019). Digital læring i askerskolen. Sluttrapport fra følgeforskning.

Tømte, C., Wollscheid, S., Bugge, M., & Vennerød-Diesen, F. F. (2018). Digital læring i askerskolen: Midtveisrapport fra følgeforskning

While this research is based on a formative dialogue research approach, impacts from research findings directly impacted the municipality's work with digitalization processes to their schools Impact from the first three years of research (2017-19) also resulted into a more focused project as previously described and recognized as Learning Tracks.

Resarchers involved in this project have also disseminated findings as opinion pieces and chronicles by engaging in the public debate on digitalization in education, below are some examples.

The chronicle 'researcher's opinion about 'screentime' in schools' aims to disseminate findings from the research on school district's approaches towards professional development of teacher's digital competence and the use of digital devices for pedagogical purposes is schools. The debate on digitalization in schools is highly polarised and emotional, hence in the chronicle the aim is to bring in some evidencebased arguments.
Chronicle in one of Norways largest newspapers (in Norwegian only):
https://www.aftenposten.no/meninger/kronikk/i/Kn1G1M/hvorfor-er-det-ingen-som-spoer-forskerne-om-bruk-av-skjermer-i-skolen

25.05.2023

This opinion piece address how digitalization in higher education has been pushed mostly by administration and IT staff, and with little involvement from teacher staff, which again has led to frustrations and limitations in pedagogical innovation caused by digital technologies.
https://www.khrono.no/er-det-pa-tide-med-ny-organisering-av-digitale-systemer/722688

The chronicle 'politicians are not to remove the digital devices from schools' aims to stress teachers' autonomy in the classroom, and that politicians should rather help and support teachers in their professional development towards digital competence, instead of aiming to steer their classroompractices.
https://www.fvn.no/mening/debattinnlegg/i/bgr8j3/aa-fjerne-skjermen-fra-skolen-er-ikke-loesningen

[University of Agder_Department of Information systems] [Case 3]

Institution: UiA
Administrative unit: Department of Information Systems
Title of case study: Responsible digitalization of Public Welfare Services
Period when the underpinning research was undertaken: 2018- today
Period when staff involved in the underpinning research were employed by the submitting institution: 2018- today
Period when the impact occurred: 2018- today

1. Summary of the impact (indicative maximum 100 words)

The impact case describes the collaboration between the department and the Norwegian Labour and Welfare Administration (NAV) concerning issues related to the responsible digitalization of public welfare services. Our research has contributed with knowledge on the responsible use of AI, channel choice management, and the inclusion of citizens within digitized service provision. We have conducted research from both a citizen- and an organizational-oriented perspective to guide NAV (and other public organizations) on how to digitize in the best possible way from the users' perspective. Our research also reflects on how to best organize in response to the opportunities provided by digital tools.

2. Underpinning research (indicative maximum 500 words)

Our work within this area focuses on "responsible digitalization," where we explore the relationship between humans and digitalization from various perspectives, based on the digitalization work of the Norwegian Labour and Welfare Administration (NAV). We do so by investigating the driving forces behind increasing digitalization that consist of both major societal challenges (such as an aging population, increased migration, changing skill needs, and the green transition) and rapid technological shifts. The work is based on an interdisciplinary approach to understand the interplay between humans, technology, and society.

The underpinning research is mainly conducted within four research projects:

Which services should be digitized and how? An analysis from a user perspective of public services suitable for digitalization. 2019- 2024, funded by NAV. Previous studies have yielded knowledge about the factors influencing citizens' channel choices. However, this research lacks insights into the distinctiveness of digital services and the interplay between citizens' perceptions of public services and their channel choices. Additionally, the crucial question of whether all public services are suitable for digitization remains unanswered. The project analyses, from a user perspective, which of NAV's public services are suitable for digital communication channel. From this insight, we identify which services - as perceived by citizens - are suitable for digitization.

What public services should be digitalised? Citizens' and public organizations' perspectives on digital welfare services in Scandinavia. 2019- 2025, funded by RCN. Based on the project above, which introduces a citizen-perspective to understand digitalization of services within NAV, this project includes an organizational perspective to explore the fit with public organizations' multi-channel management strategies. Moreover, the project includes comparative studies including both citizens and organization's perspectives within Denmark, Norway and Sweden. The research goal is concretized in four sub-goals:

1. Identify the public services that generate the most and the least traffic on digital and traditional communication channels

2. Create two analytical tools for identifying public service characteristics from (a) citizens' and (b) public organizations' perspectives
3. Explore how different characteristics of public services relate with citizens' channel choice and public organizations' multi-channel management strategies
4. Evaluate which public services should be digitalized and give guidelines how to digitalize

AI4USERS: Responsible Use of Artificial Intelligence through Design for Accountability and Intelligibility. 2020- 2025, funded by RCN. The project addresses the "black box" problem contributing to the responsible use of AI for the digitalization of public services, allowing for intelligibility and accountability. The project takes a human-centred perspective addressing the needs of different groups including citizens, case handlers and managers. Specifically, the project includes a) design, prototyping and assessing tools enabling different categories of non-experts to maintain insight into AI applications, b) formalization of the design knowledge generated in actionable design principles, c) capacity building through collaborations between academia and the public sector nationally and internationally.

Frida@Work - **Investigating human-chatbot interactions**. 2020- 2021, funded by NAV. The project investigates citizens´ interactions with NAV's chatbot Frida. The aim is to ensure that a greater number of conversations with Frida are completed, or seamlessly transferred to a human chat agent when there is a need. The project provided insights into the ways users interact with Frida and the way they experience the transition between the chatbot and human agents. And also, it provided insights into technical experts´ and chat agents´ concerns into how a chatbot can be best integrated in the workflows of digitally mediated chats.

Key researchers involved in one or more of the four mentioned projects:

- Sara Hofmann, Associate Professor, Project Manager for project one and two
- Xenia Vassilakopoulou, Professor, Project Manager for project three and four (from UiA side, the overall project was led by UiO)
- Ilias Pappas, Professor
- Øystein Sæbø, Professor
- Hanne Rydén, PhD candidate, from 2021 – today
- Ida Heggertveit, PhD candidate, from 2021 – today
- Stefan Schmager, PhD candidate, 2021- today
- Pouria Akbarighatar, PhD candidate, 2022- today

3. References to the research (indicative maximum of six references)

Hofman, S., Rydén, H. H., & Sæbø, Ø. (2024). Implications of digitalised welfare services from a vulnerable citizens' perspective. In *Nordic Welfare Research (in print)*

Lindgren, I., Madsen, C. Ø., Hofmann, S., & Melin, U. (2019). Close encounters of the digital kind: A research agenda for the digitalization of public services. Government information quarterly, 36(3), 427-436.

Rydén, H. H., Hofmann, S., & Verne, G. (2023). The Self-serving Citizen as a Co-producer in the Digital Public Service Delivery. In International Conference on Electronic Government (pp. 48-63). Cham: Springer Nature Switzerland.

Schmager, S., Grøder, C. H., Parmiggiani, E., Pappas, I., & Vassilakopoulou, P. (2023). What do citizens think of AI adoption in public services? Exploratory research on citizen attitudes through a social contract lens. In Proceedings of the 56thAnnual Hawaii International Conference on System Sciences.

Vassilakopoulou, P., Haug, A., Salvesen, L. M., & Pappas, I. O. (2023). Developing human/AI interactions for chat-based customer services: lessons learned from the Norwegian government. European Journal of Information Systems, 32(1), 10-22.

Vassilakopoulou, P., & Pappas, I. O. (2022). AI/Human augmentation: a study on chatbot–human agent handovers. In International Working Conference on Transfer and Diffusion of IT (pp. 118-123). Cham: Springer International Publishing.

4. Details of the impact (indicative maximum 750 words)

For all four projects, we have been conducting workshops and group meetings with practitioners to co-create and disseminate knowledge.

In projects one and two, we have determined how to differentiate between various public services and how these differences can aid in evaluating whether a public service is suitable for digitization from the residents' perspective. Additionally, we have analyzed how public organizations assess and differentiate between the same public services. The perspectives of residents and public organizations are combined to identify which public services should be offered online and which services should involve personal contact between residents and case handlers.

In project three researchers collaborated with NAV to develop a prototype simulating a service portal with AI-based predictions. Iterative user evaluations refined the prototype. Forty citizens provided feedback through prototype interactions, think-aloud sessions, and structured interviews. Analysis identified themes around information presentation. Considerations for implementation addressed value communication, data use scrutiny, and diverse citizen needs. The insights from this research can guide developing citizen-facing AI to maximize benefits and transparency through human-centred practices.

In project four, researchers in collaboration with NAV explored how chatbot technologies could improve human-AI interactions in chat-based customer service. Researchers participated in workshops with NAV to understand service agents' experiences using chatbots and performed interviews with agents to get insights around chatbot use. During the workshops agents were able to reflect on chatbot adaptations, refine problem definitions and conceptualize human/AI partnerships envisioning new service configurations. Three key lessons informed responsible technology use, collaboration, and innovation.

The empirical basis comprises a substantial number of individual and group interviews, as well as document analyses, to identify characteristics related to the services, the processes, and the regulatory framework. The results are discussed in workshops with key stakeholder groups, involving citizens, case handlers, and managers within NAV. Subsequently, findings are presented and discussed with various departments in NAV to explore practical implications based on our work. As part of the process, results from the projects are discussed within the research community by attending conferences and disseminating results within premier journal outlets in our field.

Based on the successful impacts from the projects, the department were invited by NAV to apply for a strategic partnership on “Responsible digitalization”. The contract was signed early 2023. It will last for four with a yearly support of 2.25 million NOK.

5. Sources to corroborate the impact (indicative maximum of ten references)

Human Centred digital transformation in NAV, Arendalsuka 17.08.22. Debate concerning human centered digital transformation of public welfare services. Hofmann & Vassilakopoulou

Pappas, I. O., Vassilakopoulou, P., Kruse, L. C., & Purao, S. (2023). Practicing effective stakeholder engagement for impactful research. IEEE Transactions on Technology and Society. 4 (3), 249–255.

Project presentation NAV FOU, Helsfyr, Oslo, 30.08.22. Presented results from projects 1 and 2 for employees in NAV (around 50 people). Sæbø, Rydén, Heggertveit

Project presentation NAV FOU, Helsfyr, Oslo, 24.08.22. Presented results from projects 1 and 2 for employees in NAV (around 70 people). Hofmann, Sæbø, Rydén, Heggertveit

Responsible digitalization in NAV, seminar at UiA, 26.04.23. Hofmann, Vassilakopoulou, Pappas, Sæbø, Rydén & Heggertveit

Schmager, S, (2022). From Commercial Agreements to the Social Contract: Human-Centered AI guidelines for Public Services. *MCIS 2022 Proceedings*.

Vassilakopoulou, P.; Pappas, I. (2022) Human Centred AI: Human-AI Partnerships for the Public Interest. Public Interest Technology Colloquium; Arizon State University, 2022-03-23

Vassilakopoulou, P. Human-Centered AI (2022). Girl Geeks Dinner, Kristiansand; 23.11.2022

Vassilakopoulou, P.; Pappas, I.(2022) Ansvarlig AI. Frokostmøte i Partnerprogrammet UiA IIS; 29.04.2022

What to gain from collaboration between NAV and the universities?, Arendalsuka 15.08.23. Sæbø

UiB Department of Informatics, impact case number 1

Institution: University of Bergen (UiB)
Administrative unit: Department of Informatics
Title of case study: Optimized cable routes in offshore wind farms
Period when the underpinning research was undertaken: 2009-2023
Period when staff involved in the underpinning research were employed by the submitting institution: 2000-
Period when the impact occurred: 2010-2016

1. Summary of the impact

For the purpose of experimental research, the optimization group developed a computer code for optimizing the layout of the cables connecting offshore wind turbines to the electrical onshore grid. The underpinning mathematical model was formulated in order to minimize the total cable length, subject to constraints such as cable capacities and avoidance of cables crossing each other. The code was first developed in collaboration with Statkraft. Later, in 2016, the ownership rights were transferred to Multiconsult, who needed the software for their consultancy projects in the offshore wind business.

2. Underpinning research

Members (mainly D. Haugland) of the optimization group were in 2009 invited by Equinor (StatoilHydro at that time) to a consultancy project devoted to optimization of the design of a floating wind turbine. This project was the group's gateway to applications in the offshore wind industry. Minimization of the costs of laying subsea cables emerged as a field with large research potential, where the group's expertise proved to be of high value. In 2010, a postdoctoral researcher (Dr. J. Bauer, a former PhD student in the group) was engaged on a three-year contract. Jointly with Prof. J. Lysgaard from Aarhus University, Denmark, she developed a model that outputs a cable layout that respects constraints like connectivity, cable capacity, and avoidance of self-crossing cable routes. Owing to their numerous occurrences in even small instances of the problem, the latter constraints are particularly challenging. To cope with this, a constraint-generating algorithm that filters out superfluous constraints was developed. This feature turned out to be crucial for the practical applicability of Bauer and Lysgaard's model. By the end of her tenure, Dr. Bauer collaborated with Statkraft on applying a computer implementation of the model and the algorithm to a real case.

During the engagement of PhD student A. Klein in 2012, the group's work on offshore wind applications, cable layout optimization in particular, was intensified. Models and associated solution methods were found for the problem of avoiding obstacles and exploiting trenches shared between several cables. Likewise, the methodology of Bauer and Lysgaard was extended to reflect the need for redundancy in the cable network, targeting robust networks in cases where break-downs are likely to occur. The research was partly of a theoretical nature, but its empirical, experimental component was dominant throughout. Computer implementations, mainly intended for experimental purposes, were made in all phases of the research. Results were published in international energy and operations research journals (see Section 3 below).

3. References to the research

Bauer, J., Lysgaard, J. (2015): The offshore wind farm array cable layout problem: a planar open vehicle routing problem, *Journal of the Operational Research Society*, 66(3), pp. 360-368, https://doi.org/10.1057/jors.2013.188.

Klein, A., Haugland, D., Bauer, J., Mommer, M. (2015). An integer programming model for branching cable layouts in offshore wind farms. *Advances in Intelligent Systems and Computing*, 359, pp. 27–36, https://doi.org/10.1007/978-3-319-18161-5_3.

Klein, A. (2016): A continuously differentiable turbine layout optimization model for offshore wind farms, *Energy Procedia*, 94, pp. 497-503, https://doi.org/10.1016/j.egypro.2016.09.221.

Klein, A., Haugland, D. (2019): Obstacle-aware optimization of offshore wind farm cable layouts, *Annals of Operations Research*, 272(1-2), pp. 373-388, https://doi.org/10.1007/s10479-017-2581-5.

Klein, A. (2019): Methods for Optimizing Turbine Locations and Cable Routes in Offshore Wind Farms, PhD thesis, ISBN 978-82-308-3569-2, University of Bergen, Norway.

Klein, A., Haugland, D. (2021): Optimization of reliable cyclic cable layouts in offshore wind farms, *Engineering Optimization*, 53(2), pp. 258-276, https://doi.org/10.1080/0305215X.2020.1717482.

4. Details of the impact

Through informal contacts, the group's early work on cabling problems in offshore wind was brought to Statkraft's attention. An agreement on collaboration between the company and UiB was established in 2013. The purpose was to apply a preliminary version of the experimental software under development to a real case (Dudgeon Offshore Wind Farm) owned by a subsidiary (Dudgeon Offshore Wind Limited) of Statkraft and other energy companies. Thus, Bauer delivered consultancy services to Statkraft for a shorter period, and proprietary rights of a version of the computer code were transferred to the company. Awareness of the tool propagated to other consultancy agencies working on cabling in offshore wind farms, including Multiconsult, who had Statkraft as a major client.

After Dr. Bauer's postdoctoral tenure ended in 2013, the research continued, now with Klein's PhD thesis in a pivotal role. In spring 2016, Multiconsult expressed interest in acquiring the ownership rights to the software, to which Statkraft at that time still had proprietary rights. Through an agreement with UiB, these rights were waived, and ownership rights were transferred to Multiconsult later in the same year. The technology transfer office at UiB (*Bergen Teknologioverføring AS*, now *VIS*) was assigned the responsibility of processing the transfer. In accordance with the Norwegian *employee inventors act*, one part of the transfer fee was credited to Bauer (50%), Haugland (25%), and Klein (25%).

The product acquired by Multiconsult was deeply rooted in the research of the optimization group at the Department of Informatics. All its parts originated from computer code that was extensively used in the experiments documented in the publications listed in Section 3. Likewise, impact in the reverse direction has been observed in terms of research and master student theses reflecting industrial needs revealed during the above-mentioned collaboration. While the impact was accomplished already in 2016, the related research has been pursued until the current date.

5. Sources to corroborate the impact

Sverre Skalleberg Gjerde, Multiconsult (now at Equinor)
Jarle Eek, Statkraft
Karstein Brekke, Statkraft
Dag Finne (VIS), +47 92016360, dfi@visinnovasjon.no

UiB Department of Informatics, impact case number 2

Institution: University of Bergen (UiB)
Administrative unit: Department of Informatics
Title of case study: Type-safe templates in the Fortran programming language
Period when the underpinning research was undertaken: 2010-2015
Period when staff involved in the underpinning research were employed by the submitting institution: 2010-present
Period when the impact occurred: 2019 onwards

1. Summary of the impact

Fortran is one of the 20 most popular programming languages worldwide (see Tiobe index for 2023) and is mainly used for scientific/high-performance computing , e.g., weather forecasts, climate research, physics. Generic programming is a flexible code reuse approach which improves both productivity and software quality. It was made popular by the *template* mechanism in the programming language C++. Researchers at the Department of Informatics significantly contribute to the development of a *type-safe template* feature for Fortran. Type-safety eliminates the convoluted error messages that may occur with C++ templates, and enable new, safer software practices, e.g., proof-by-testing.

2. Underpinning research

The DMPL project (Design of a Mouldable Programming Language, 2010-2015) funded by the Research Council of Norway (RCN) had as its goals to design and implement tools (IDE, compiler) for a mouldable programming language, where mouldable means a language with a very flexible reuse mechanism integrating safety features and formal specifications. The outcome was the language Magnolia based on Goguen/Burstall institution theory: integration of formal specifications and program code with a powerful type-safe generic reuse mechanism.

After the project ended, research related to Magnolia has continued. Since 2014, Magnolia has been used in the department's course INF220 (Software Specification). The Magnolia library now contains more than 750 specification modules composed from 1350 individual axioms, 800 generic implementations and 250 applications, ranging from simple tutorial and test applications to PDE solvers running on GPUs and high-performance computers (HPC). An insight from the project is the use of Magnolia as a lightweight approach to domain and requirements engineering (in the Dines Bjørner sense). Domain engineering the Magnolia way is useful for defining programming APIs, e.g., in the domain of partial differential equation (PDE) solvers. PDE solvers are typical applications in the HPC domain.

The extensive experience with type-safe generic programming and its relevance for the high-performance domain was the setting when Professor Magne Haveraaen, Department of Informatics, UiB, was invited to present these perspectives for the ISO Fortran standards committee in 2019. The insights were summarised in the position paper "Reflecting on generics for Fortran", coauthored by Jaakko Järvi and Damian Rouson. Järvi has experience with C++ standardisation and C++ concepts, a type-safe mechanism put forward for C++ 2011 templates though rejected by the ISO C++ standards committee. Rouson is a long-term proponent of Fortran and a member of the Fortran standards committee.

Key people linked with the Department of Informatics (UiB) in the DMPL project and continued research:

- **Professor Magne Haveraaen, PI for DMPL**
- DMPL Postdoc Anya Helene Bagge, from 2016 an associate professor at the department
- DMPL Postdoc Eva Burrows, left the department when the project ended
- DMPL PhD Tero Hasu, left the department when the project ended
- DMPL partner Helmer André Friis, employed at IRIS in Stavanger
- DMPL visitor professor Dines Bjørner, May 2012, from Technical University of Denmark, a key proponent of the Danish school of the Vienna Development Method (VDM)
- DMPL visitor Damian Rouson, summer 2012, then employed at Sandia Laboratories, USA
- PhD Benjamin Chetioui 2019-2022
- Professor Jaakko Järvi, sabbatical in Bergen spring 2014, professor in Bergen 2016-2020, since then adjunct professor at the department (main position at University of Turku from 2020)
- Postdoc Mikhail Barash 2020-2023, since 2023 associate professor at the department
- Several master students

3. References to the research

- Magne Haveraaen, Karla Morris, Damian W. I. Rouson, Hari Radhakrishnan, Clayton Carson: High-Performance Design Patterns for Modern Fortran. Sci. Program. 2015: 942059:1-942059:14 (2015). https://doi.org/10.1155/2015/942059
- Magne Haveraaen: Domain Engineering the Magnolia Way. Ershov Informatics Conference 2017 (LNCS 10742): 196-210. https://doi.org/10.1007/978-3-319-74313-4_15
- Eva Burrows, Helmer André Friis, Magne Haveraaen: An array API for finite difference methods. ARRAY@PLDI 2018: 59-66. https://doi.org/10.1145/3219753.3219761
- Magne Haveraaen: Proving a core code for FDM correct by 2 + dw tests. ARRAY@PLDI 2018: 42-49. https://doi.org/10.1145/3219753.3219759
- M. Haveraaen, J. Järvi, and D. Rouson, "Reflecting on generics for Fortran," 2019, presented at the Fortran Standardisation Meeting, ANSI PL22.3 (J3) & ISO/IEC JTC 1/SC 22/WG 5 in Tokyo (JP), 2019-08-05 through 2019-08-09. https://j3-fortran.org/doc/year/19/19-188.pdf
- Benjamin Chetioui, Marius Kleppe Larnøy, Jaakko Järvi, Magne Haveraaen, Lenore Mullin: P3 problem and Magnolia language: Specializing array computations for emerging architectures. Frontiers Comput. Sci. 4 (2022). https://doi.org/10.3389/fcomp.2022.931312
- Benjamin Chetioui, Jaakko Järvi, Magne Haveraaen: Revisiting Language Support for Generic Programming: When Genericity Is a Core Design Goal. CoRR abs/2211.01678 (2022)

The latter paper has since been published in Art Sci. Eng. Program. 7(2) (2023). https://doi.org/10.22152/programming-journal.org/2023/7/4

4. Details of the impact

Impact

Fortran is a major programming language in the scientific/high-performance domain. It is heavily used in areas like climate research, weather forecasting, astronomy and physics in general. A template feature is a flexible code reuse mechanism, simplifying and enhancing use of code libraries by instantiating them with the using context's types and operations. This improves productivity and indirectly improves code quality since library code in general will be of higher quality than user developed code. In addition, type-safe templates open new approaches to improving software quality, e.g., by fine-grained domain-oriented typing and

possibly proof by testing. A template feature (generics) was the most wanted extension of Fortran in a survey of Fortran users by the Fortran committee after the 2018 standard was released. At the time members of the committee had a disparity of ideas on generics features.

The paper "Reflecting on generics for Fortran" was presented by Haveraaen as a tutorial Tuesday 2019-08-06 at the WG5 (ISO Fortran) meeting in Tokyo, Japan. After several discussion rounds at the meeting, the ideas presented in this position paper were unanimously taken as the guiding principles for the design of the Fortran templates feature.

The position paper summarised insights from the DMPL project and later work on Magnolia:

- Formal generic parameters should be types, operations with full prototype declarations or typed values, and generic code must be fully type-checked against these constraints.
- Generic arguments should allow both intrinsic and user defined (derived) types and operations, and the instantiation should be fully checked against the prototype declarations.
- Nested generic definitions should be allowed (e.g., a generic module inside a generic module). This allows for flexible structuring of generic definitions
- In the using context, when instantiating generic code, it should be possible to rename the defined types and operations.
- Reusable renaming lists should be supported.

The paper also contained references to and experience with templates (generics) in other languages, e.g., C++ and Java.

The template feature is currently on track to be included in the next revision of the Fortran standard, expected to be published in 2028.

ISO and INCITS Fortran standardisation

ISO/IEC JTC 1/SC 22 (Programming languages, their environments and system software interfaces) is a standardisation subcommittee of the Joint Technical Committee ISO/IEC JTC 1 of the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC). The secretariat of SC 22 is the American National Standards Institute (ANSI). The InterNational Committee for Information Technology Standards (INCITS) is the ANSI-accredited standards organisation which coordinates standardisation activities between ANSI in the US and joint ISO/IEC committees worldwide.

The ISO standard for Fortran is decided by the member countries of ISO/IEC JTC 1/SC 22/WG 5, known as WG5. The development of the Fortran standard is handled by the INCITS working committee for Fortran, informally known as J3. Members of J3 are companies (mostly Fortran compiler providers), national labs (Fortran users), other interested organisations and individuals, in total 14 members with 39 alternates, all together 53 recognised participants.

J3 meets 3 times per year, while WG5 meets once per year, typically coordinated with the J3 summer meeting.

Proposals for the evolution of Fortran are forwarded to J3 as papers which are then discussed in plenary at the meetings and ultimately being voted upon. Typically, a proposal will go through many iterations before being accepted. For a fundamental feature like type-safe templates, such a process will take many iterations over several years.

Work on type-safe templates in Fortran
A special subgroup of the Fortran committee was set up by J3 to develop a concrete proposal for type-safe Fortran templates. The "generic subgroup"'s leader is Tom Clune (NASA), with Brad Richardson (Lawrence Berkeley National Lab) and Haveraaen (UiB) as the most active members. The Fortran compiler teams at Intel and Nvidia are regular participants in the work, with other interested participants intermittently airing ideas and coming with suggestions.

The generics subgroup has weekly online meetings producing a stream of papers. Paper iterations of requirements, specifications and specific aspects of the design has been put before J3 and accepted. A paper trail is available on J3's web site https://j3-fortran.org

Prototype implementation of Fortran templates
Ahead of final standardisation, the open source LFortran compiler currently provides a prototype implementation of type-safe templates. The LFortran compiler runs in the browser from https://dev.lfortran.org and the online version contains several example codes demonstrating type-safe templates Fortran style. Haveraaen (UiB) is providing advice on the implementation of the type-safe template extension during biweekly online meetings with the LFortran development team.

5. Sources to corroborate the impact (indicative maximum of ten references)
Designing type-safe templates for Fortran is an ongoing activity in the Fortran committee. The status per late 2023 is that the template design is accepted, and concrete syntax is being discussed.

- 23-103r1 (Generics formal requirements) passed
- 22-151r3 (Specs for generics scoping) passed
- 22-154r5 (Generics formal specs) passed
- 23-104r1 (Formal specs for TEMPLATE) passed
- 23-222 (Formal syntax for generics) deferred
- 23-236r2 (Templates in CONTAINS section) info

Tutorials and outreach

- 22-165 (Generics Tutorial) info
- 22-202 (Generics tutorial – generics/examples/fundamental_requirements) info
- 23-204 (Templates Tutorials) info
- The future of HPC programming - a Modern Fortran workshop, video recording of a two-day workshop, November 2022, Umeå (SE)

The status field attached to each Fortran standards committee reference indicates:

- passed: paper has been voted on and accepted by the INCITS Fortran committee
- info: paper put before the committee for information only
- deferred: discussion and voting postponed for a later meeting

UiB Department of Informatics, impact case number 3

Institution: University of Bergen (UiB)
Administrative unit: Department of Informatics
Title of case study: Characteristics of the New Personal Identifier
Period when the underpinning research was undertaken: 2011-2013
Period when staff involved in the underpinning research were employed by the submitting institution: the period includes at least from 1990th to 2017 (one person retired)
Period when the impact occurred: 2017-2018 and from 2032

1. Summary of the impact

The Norwegian personal identifier (PID) system is used across all parts of public administration in Norway. The National Population Register recognized the need to address the projected shortfall in the current PID capacity by 2040, necessitating a new PID that meets critical needs including sufficient capacity of over 900 unique values per date by 2150, cost-efficiency, and ease of use. The Selmer Center proposed four alternatives for the new PID during 2012-2013. The Tax Directorate assessed the impact of each option, and the new PID with sufficient capacity and minimum economic and administrative cost is planned for adoption in 2032.

2. Underpinning research

The Tax Directorate launched a project to develop new PIDs, addressing the limitations of the current PIDs (the social security number for long-term residents and the D-number for short-term stays in Norway). The existing PID, designed in the 1960s by Ernst Selmer, consists of 11 digits formatted as $DDMMYYI_1I_2I_3K_1K_2$, where the first 6 digits DDMMYY indicate a person's birth date, the 3 digits $I_1I_2I_3$ are individual numbers carrying relevant information like gender and birth century, and the last two K_1K_2 are check digits for error control. The three-digit individual number $I_1I_2I_3$ was originally devised considering the size of the population and the maximum number of births on any given day of the year in mind. However, with the growing population due to immigration and other factors, it is evident that the capacity of existing PID (the maximum number of unique values for every birth date) is insufficient to meet future demands.

The initiative for a new PID in the National Population Register in 2011 set three absolute and four important requirements within the scope of capacity and privacy. Three absolute requirements are 1) capacity for the current registry population at least until 2150; 2) each person should have a unique personal identifier; 3) compliance with current regulations for privacy and security. Important requirements include low implementation risk, high user-friendliness, efficient control routines, etc. There are two dimensions for the new PID design: 1) alphanumeric or numeric; 2) information-bearing or non-information design.

Professors Tor Helleseth and Øyvind Ytrehus, both full-time faculty members at the Selmer Center at the time, were commissioned to evaluate the capacity of the existing PID and to assess new PID alternatives. They delivered three detailed evaluation reports on April 23th 2012 and April 4th 2013. These reports examined 8 alternatives based on various criteria, including comparison between information-bearing and non-information design, capacity, error detection and correction, length, ease of memorization, alphabet and size of the character set, compatibility with past and future systems, expandability, uniqueness, implications for software

changes, technological considerations, and implications for data security and privacy. These criteria were evaluated from information-theoretic, technical and societal viewpoints.

Upon their technical evaluation, four alternatives (two information-bearing and two not) were further assessed through a systematic socio-economic analysis. These incorporated a range of cost factors pertinent to sectors such as healthcare, municipal services, state enterprises whose core operations involve personal data management (like NAV, UDI, and Statistics Norway), and the financial industry. The financial implications of implementing the four proposed alternatives spanned a broad spectrum, with estimates ranging from 2.16 billion to 18.82 billion Norwegian kroner. Ultimately, the authority settled Alternative 1 for the new PID design, which maintains the best compatibility with the existing PID. This alternative has the same $DDMMYYI_1I_2I_3K_1K_2$, where the associated checksum S1 modulo 11 takes values ranging from 1 to 10, and the associated checksum S_2 modulo 11 is equal to 0, which can be loosen to 1, 2, …, 10 when needed in future. This design offers attractive backward compatibility, extensibility and error control.

3. References to the research

- Tor Helleseth, Øyvind Ytrehus, Rapport om egenskaper ved ny personidentifikator, del 1. s.l. : Selmersenteret, Universitetet i Bergen, 2012.
- Tor Helleseth, Øyvind Ytrehus, Rapport om egenskaper ved ny personidentifikator, del 2. s.l. : Selmersenteret, Universitetet i Bergen, 2013.
- Tor Helleseth, Øyvind Ytrehus, Rapport om D-nummer og økt populasjon for personidentifikator. s.l. : Universitetet i Bergen/Selmersenteret, 2013

The reports (in Norwegian) are enclosed as attachments in the government report at the following link
https://www.skatteetaten.no/globalassets/om-skatteetaten/analyse-og-rapporter/rapporter/rapport_ny_personidentifikator_i_folkeregisteret-2013.pdf

4. Details of the impact

In association with significant governmental investments on the transition of new PIDs, external quality assurance is mandated. This process adheres to the framework agreement established with the Ministry of Finance on March 4, 2011. The objective of this quality assurance scheme is to furnish the Ministry of Finance, as well as the relevant Ministry of Education, with an impartial analysis concerning

- The selection of the concept prior to the submission of proposals for preliminary projects to the Government (KS1).
- The foundational documents for governance and cost estimates before presenting the selected project alternative to the Parliament (KS2).

The conclusions and recommendations were formally delivered to the client on November 16, 2015.

Professors Tor Helleseth and Øyvind Ytrehus at the Selmer Center were commissioned to evaluate the technical aspects of the existing PID and new PID alternatives. Their conclusion and recommended alternatives in the 3 evaluation reports were further assessed by other sectors (like Dovre Group, Tax Directorate and the Department of Finance) from perspectives of economic, societal and administrative impacts to the society. The recommended Alternative 1 for the new PID is planned for adoption from Jan. 2032. As listed in the government's website (here), the PID transition involves 80 institutions and organizations, such as Ministry of Labour and Social Affairs, Ministry of Children, Equality and Social Inclusion, Ministry of Defence, Ministry of Health and Care Services, Ministry of Education and Research, The Directorate of

eHealth, The Directorate of Financial Management, The Financial Supervisory Authority of Norway, The Government Pension Fund Norway, etc.. The 80 sectors represent a broad spectrum of Norwegian civil society, including sectors such as labor and social affairs, children and equality, defense, health care, justice and emergency preparedness, climate and environment, local government, culture, education, agriculture, business and fisheries, oil and energy, transportation, foreign affairs, and various professional and interest groups. As of 22.06.2017, 46 sectors and organizations responded to the PID transition. The broad spectrum of impacted sectors in Norway reflects the importance of adopting a new PID that are most suitable for all aspects. Thanks to the technical soundness, cost-effectiveness and versatility of Alternative 1, it was finally chosen as the new PID, which, according to Table 12 in this report, potentially saved financial cost up to 16.6 billion NOK for the whole society in Norway.

5. Sources to corroborate the impact

1. Ernst S. Selmer: Personnummerering i Norge: Litt anvendt tallteori og psykologi, *Nordisk matematisk tidsskrift* **12**, 36–44, Oslo 1964
2. Norwegian Tax Directorate, Konseptvalgutredning-Ny personidentifikator i Folkeregisteret, version 1.0, 2013, avaiable at this link
3. Norwegian Tax Directorate, Konseptvalgutredning-Ny personidentifikator i Folkeregisteret, version 1.3, 2015, avaiable at this link
4. Dovre Group Transportøkonomisk institutt, Ny personidentifikator i Folkeregisteret, Kvalitetssikring av beslutningsunderlag for konseptvalg (KS1), 2015, available at this link
5. Department of Finance, Forslag til ny personidentifikator, 2017, available at this link
6. Norwegian Tax Directorate, New national personal identificator and D-number from 2032, available at this URL

University of Bergen, Department of Mathematics [1]

Institution: University of Bergen
Administrative unit: Department of Mathematics
Title of case study: Knowledge for off-shore CO_2 storage
Period when the underpinning research was undertaken: 2002-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2002-2022
Period when the impact occurred: 2013-current

1. Summary of the impact

Norway is in the process of launching one of first commercial CO_2 transport and storage projects globally. Researchers at the Department of Mathematics, in particular the porous media and fluid dynamics groups, have been extensively involved in the knowledge development which has allowed this project to mature from the conceptual stage to become a viable commercial undertaking. In particular, our research 1) provided one of the first quantitative assessments of the Johansen formation as a storage site, 2) has contributed to the development and validation of the computational tools that have been used for site assessment, 3) have contributed knowledge to the environmental risk assessment, and 4) have been highly visible in forming public perception.

2. Underpinning research

Research on aspects of CO_2storage was initiated at the Department of Mathematics in 2002 with the project "Safe long terms storage of CO_2 in aquifers" and has continued until the present. Throughout this period, the research has been organized in projects with significant stake-holder involvement, both nationally and internationally. In total, nearly 50 journal papers have been published by researchers affiliated with the department in the period 2002-2022 on this topic. Of this research, we highlight below the results that have had the most direct impact on the current development of commercial-scale CO_2 storage in Norway.

On a physical process level, storage of CO_2 deviates substantially from petroleum production in several ways. Most obviously, the substance of interest is injected rather than produced, and thus it is the migration away from wells, rather than the flow towards them, that is of importance. More subtly, the CO_2-water-salt-mineral system is strongly impacted by phase transitions and salt precipitation (and even mineral dissolution), in ways that are significantly different from what is seen in most oil-gas-water systems. This implies that standard computational tools developed for petroleum production, and the understanding learned from them, cannot be directly transferred CO_2 storage. An overarching motivation for the research undertaken in the porous media group has therefore been to 1) Provide general knowledge of CO_2 storage processes. 2) Verify and validate the applicability of existing and new computational tools for simulating CO_2 storage. 3) Provide case studies that can serve as benchmarks for researchers, industry, and regulators. Cornerstone publications of such results are summarized in references [1-6] below.

Geological CO_2 storage, like all industrial developments, carries risks. Regulatory-required Environmental Impact Assessments (EIAs) and Measurement, Monitoring and Verification (MMV) ensure safety in subsea CO_2 storage projects. With the expected rise in offshore storage projects for carbon sequestration, the low yet increasing risk of CO_2 leakage necessitates cautious monitoring of both subsurface and marine environments around storage sites. The department, backed by national and international funding, has developed tools like the ACTOM toolbox to assess potential impacts of CO_2 seepage on marine waters, aiding operators and governments in meeting regulatory and societal expectations.

The research described in this impact case was conducted within the Porous Media Group and the Fluid Dynamics Group. The professors responsible for the research were Guttorm Alendal, Inga Berre, Helge Dahle and Jan Martin Nordbotten. Additionally, the following researchers contributed: Geir Terje Eigestad (post.doc and Associate Professor until 2007), Paolo A. Herrera (post.doc 2009-2011), Eirik Keilegavlen (post.doc 2010-2012, permanent researcher since 2012), Anna Olyenik (post.doc 2017-2020, permanent researcher since 2020) and Alfatih Ali (post.doc 2012-2014). Further contributing to the research were numerous MSc and PhD students, as well as national and international research partners as detailed below.

The following projects were central for the research and dissemination described herein.

Project 1: Safe Long Terms Storage of CO_2 in aquifers 2003-2006	**Project owner**	UoB
	Total budget	13 MNOK
	Funding partners Research Council of Norway, Norsk Hydro	**Research partners** Dept. of Physics and Technology (UoB) and Department of Mathematics
Project 2: Geological Storage of CO_2: Mathematical Modeling and Risk Assessment (MatMoRA) 2007-2011	**Project owner**	UoB
	Total budget	21.6 MNOK
	Funding partners Research Council of Norway, CLIMIT, Statoil ASA, A/S Norske Shell	**Research partners** SINTEF, Uni CIPR
Project 3: Capacity of large-scale CO_2 storage in North Sea sloping aquifers from numerical simulation (LCSANS) 2013-2016	**Project owner**	Uni Research
	Total budget	8.8 MNOK
	Funding Partners Research Council of Norway CLIMIT, Total Energies, RWE DEA Norge, Foundation CMG	**Research partners** Uni CIPR, UoB
Project 4: Sub-seabed CO_2 Storage: Impact on Marine Ecosystems (ECO2) 2011-2015	**Project owner**	GEOMAR, Germany
	Total budget	14 M€
	Funding Partners EU FP7, Statoil (now Equinor)	**Research partners** Uni CIPR, Uni Climate, Plymouth Marine Laboratory and Heriot-Watt University 24 more across Europe.
Project 5: Strategies for Environmental Monitoring of Marine Carbon Capture and Storage (STEMM-CCS) 2016-2020	**Project owner**	National Oceanography Center, Southampton, UK
	Total budget	16 M€
	Funding Partners H2020 funding, Shell	**Research partners** Uni CIPR, Uni Climate, Plymouth Marine Laboratory 10 more across Europe.
Project 6: Act on Offshore Monitoring (ACTOM) 2019-2023	**Project owner**	UoB
	Total budget	2.0 M€
	Funding Partners The Research Council of Norway, Ministry of Economic Affairs and Climate Policy (NL), Department for	NORCE, Octio, Plymouth Marine Laboratory (UK), University of Dundee (UK), TNO (NL), Los Alamos National Laboratory (USA),

	Business, Energy & Industrial Strategy (UK), Department of Energy (USA)	University of Texas at Austin (USA).

3. References to the research

Bibliometric identification	Relevance for Impact	Contribution
[1] Eigestad, G.T., Dahle, H.K., Hellevang, B. et al. (2009), *Geological modeling and simulation of* CO_2 *injection in the Johansen formation*. Comput Geosci 13, 435–450. https://doi.org/10.1007/s10596-009-9153-y	Possibly the first CO_2 storage assessment published for the Johansen formation, the current target formation for Northern Lights	Study lead, and contribution to all aspects of the work.
[2] Nordbotten, J. M. and M. A. Celia (2011), *Geological Storage of* CO_2*: Modeling Approaches for Large-Scale Simulation*, John Wiley and Sons, Ltd, 256 pp, ISBN: 9780470889466. https://doi.org/10.1002/9781118137086	The first text-book consolidating state-of-the-art knowledge on modeling and simulation of CO_2 storage	First author, and contributions to all aspects of the work.
[3] Nordbotten, J. M., B. Flemisch, S. E. Gasda, H. M. Nilsen, Y. Fan, G. E. Pickup, B. Wiese, M. A. Celia, H. K. Dahle, G. T. Eigestad, K. Pruess (2012), *Uncertainties in practical simulation of* CO_2 *storage*, International Journal of Greenhouse Gas Control, 9, 234-242. https://doi.org/10.1016/j.ijggc.2012.03.007	International assessment of limitations of current simulation technologies for CO_2 storage.	Study lead, and contribution to all aspects of the work.
[4] Nordbotten, J. M., Fernø, M., Flemisch, B., Juanes, R., Jørgensen, M. (2022), *Final Benchmark Description: FluidFlower International Benchmark Study*. https://doi.org/10.5281/zenodo.6807102	Recent work on validating CO_2 simulation technology, included in the museum exhibit described below	Study lead, and contribution to all aspects of the work.
[5] Hvidevold HK., Alendal, G., Ali A.; Johannessen T., Mannseth T., & Avlesen H**.** (2015**).** Layout of CCS monitoring infrastructure with highest probability of detecting a footprint of a CO_2 leak in a varying marine environment. *International Journal of Greenhouse Gas Control,* Volume 37, June 2015, Pages 274-279. http://dx.doi.org/10.1016/j.ijggc.2015.03.013.	Optimal placement of fixed instrumentation based on modelling of tracer transport	Study lead, Conceptualization, Methodology, Writing - Review & Editing
[6] Alendal, G. (2017). Cost efficient environmental survey paths for detecting continuous tracer discharges. *Journal of Geophysical Research-Oceans*, *122*(7), 5458–5467. http://doi.org/10.1002/2016JC012655 https://doi.org/10.1016/j.ijggc.2021.103310.	Optimal routing of moving platforms based on tracer simulations and Bayesian statistics.	Study lead, Conceptualization, Methodology, Writing - Review & Editing
[7] Blackford, J., Alendal, G**.**, Avlesen, H., Brereton, A., Cazenave, P. W., Chen, B., et al. (2020). Impact and detectability of	This publication summarizes the findings from several	Conceptualization, Methodology, Writing - Review & Editing

hypothetical CCS offshore seep scenarios as an aid to storage assurance and risk assessment. *International Journal of Greenhouse Gas Control*, 95, 102949. http://doi.org/10.1016/j.ijggc.2019.102949	modelling studies, including ECO2 and STEMM-CCS.	

4. Details of the impact

In 2013, the Norwegian Government decided to explore the possibility for a large-scale commercial Carbon Capture and Storage (CCS) value chain, with the goal of subsea CO_2 storage off the Western Norwegian coast. Among other aspects, this process involved a concept study by the government-owned company Gassnova in 2015, and led to the formation of the joint venture "Northern Lights" between the major oil companies Equinor, Total Energies, and Shell. Having identified a suitable target for CO_2 storage in the Johansen Formation, as of the end of 2022, the facilities for transport and storage of CO_2 are currently being built.

Site selection and planning of CO_2 storage is intrinsically built around simulation technology and required a significant amount of new conceptualization and adaptation of existing simulation technology [2]. The porous media group at the Department of Mathematics had in the relevant period of 2003-2015 collaborative projects involving all three companies in the joint venture Northern Lights development: This includes MatMoRA (Equinor [then Statoil], and Norske Shell) and LCSANS (Total Norge, Wintershall DEA Norge [then RWE DEA Norge], Foundation CMG). These projects had as overall themes the development of reliable computational tools for assessing storage capacity and understanding leakage risk, and publications from these projects involved among other results one of the first site studies for the Johansen formation, with data released to the public domain [1]. The research group has also consistently strived to contribute to understanding the confidence that can be ascribed to various simulation technologies, through leading roles in community-wide benchmark studies [3, 4].

Several students and researchers who were involved in the above-mentioned projects later worked for companies in the CCS value chain and various government owned research institutes, providing another important vector for knowledge transfer. One notable example is Wintershall DEA Norge, who were partners in the LCSANS project: Our former colleague Eigestad has now worked for the company since 2017, and in 2022 they acquired their first license for CO2 storage offshore Norway.

Potential impact and our ability to distinguish the characteristics of a CO_2 seep to marine waters has been addressed through several projects, starting with national projects funded through the Research Council of Norway (CO2marine and CO2base, 2010-2014). In the FP7 funded ECO2 project, that used natural analogues to study CO_2 behavior in the water column, the department had WP lead for the modelling activities. In the following H2020 funded project, STEMM-CCS, the department took part in experimental design and subsequent data analysis on the groundbreaking in-situ release off the coast of Scotland. As a direct consequence of these activities the department coordinated the ACTOM project, in which a highly cross-disciplinary project team built the Decision Support Tool (DST) for designing environmental monitoring programs. A report, presented in a webinar with 130 participants from worldwide, presented the legal requirements from national and international legislation and conventions have on MMV in view of technological capabilities. The project demonstrated the toolbox on potential storage sites in the North Sea, Norwegian and Dutch sector, and in the Gulf of Mexico. The department has primarily contributed scientifically through mathematical modelling for impact assessments and designing monitoring programs [5,6,7].

Throughout this period the department has been active in dissemination of our research related to CCUS technology in various settings, such as the IEAGHG network meetings on monitoring and risks, the biannual Greenhouse Gas Technology conferences, and in national CLIMIT days. In February 2020 the department organized the STEMM-CCS open science meeting & 4th International Workshop on Offshore Geologic CO2 storage with 150 global participants.

As a final indication of the impact of the research, the University Museum of Bergen selected porous media in general as the topic of a one-year special exhibit. Here, CO_2 storage was the key example of the exhibit, and particular emphasis was placed on the learnings from research at the University of Bergen. The exhibit attracted visitors from both industry and the highest level of government. The temporary exhibit was complimented by the development of a permanent pedagogical activity for junior high school and high school students in Western Norway, wherein they learn about CCS both from an environmental, societal and technological perspective. In addition the activities has been presented in popular science channels, such as forskning.no and during Arendalsuka, the largest political gathering in Norway.

The research outlined above has thus directly contributed to the knowledge base, as well as the human resources, for government agencies, research institutes and operating companies, within the context of developing CCUS as a viable industry in Norway and internationally.

5. Sources to corroborate the impact

1. Contributing to the development of Johansen formation as a storage site:
https://ccsnorway.com/no/historien-om-johansen-formasjonen/
https://www.sodir.no/aktuelt/nyheter/generelle-nyheter/2020/undersjoisk-co2-lagring-historien-om-johansen-formasjonen/

2. Release of public dataset for Johansen:
https://co2datashare.org/dataset/the-johansen-dataset
https://www.sintef.no/projectweb/mrst/modules/co2lab/

4. Lead on community-wide validation benchmark for CO_2 storage modeling 2021-2023:
https://fluidflower.w.uib.no/fluidflower-international-benchmark-study/

5. International collaboration and networking
https://www.stemm-ccs.eu/OSM-IOW
http://www.us-norway-ccus.com/new-page-1
https://documents.ieaghg.org/index.php/s/iXxC7b7SF5mR7hr

6. Public outreach and communication
https://www.uib.no/forskningskommunikasjon/151472/v%C3%A5r-por%C3%B8se-verden
https://www.uib.no/forskningskommunikasjon/63732/skolebes%C3%B8k#videreg-ende
https://www.forskning.no/co2-havet-klima/co2-lagring-under-havbotnen-krev-effektiv-miljoovervaking/1618225
https://program.arendalsuka.no/event/user-view/11915?redir=
https://actom.w.uib.no/webinars/

7. The ACTOM Decision Support Tool:
https://www.pml.ac.uk/science/projects/ACTOM-Decision-Support-Tool
https://zenodo.org/records/10246238

University of Bergen, Department of Mathematics. [2]

Institution: University of Bergen
Administrative unit: Department of Mathematics, Statistics and Data Science group
Title of case study: Statistical methods within laboratory medicine
Period when the underpinning research was undertaken: 2014-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2014-2022
Period when the impact occurred: 2018-2022

1. Summary of the impact (indicative maximum 100 words)

Laboratory medicine is a medical science focusing on analysing laboratory tests in e.g. blood and urine samples, to aid in the diagnosis, monitoring and treatment of diseases. The field of statistics is fundamental in maintaining quality control procedures for laboratories as well determining reference limits, biological variation and designing clinical trials.

The Norwegian Organization for Quality Improvement of Laboratory Examinations (Noklus; www.noklus.no) located in Bergen, provides quality improvement services for about 3500 medical laboratories e.g. circulating quality control materials. Over several years, the research collaboration between the Statistics and Data Science group at the Department of Mathematics, UiB, and Noklus, concerning the use of statistical methods within laboratory medicine, has impacted the way Noklus, and similar international organizations, uses statistical techniques in their work. This improvement has benefitted laboratories and receivers of healthcare.

2. Underpinning research (indicative maximum 500 words)

The research has been conducted over a number of years in a close collaboration between Department of Mathematics, UiB and Noklus, Haraldsplass Deaconees Hospital. In addition, foreign partners have contributed in parts of the research. The main research area is how to improve the use of statistical methods in laboratory medicine and clinical chemistry.

The research has been primarily funded by two grants from Helse Vest RHF (the Western Norway Regional Health Authority), in addition a PhD-position and research time funded directly by Noklus. Furthermore, own financing from the Department of Mathematics, UiB, over the whole time period 2014-2022 (and further work is still ongoing). The research projects are as follows:

a. "Experimental designs and statistical methods for estimating variance components in studies of biological variation", project funded by Helse Vest RHF, period 2014-2016. Key researchers:
    a. Professor and leader of Noklus Sverre Sandberg (main supervisor)
    b. PhD-student Thomas Røraas, Noklus
    c. Associate Professor Bård Støve, Department of Mathematics, UiB (co-supervisor)
    d. Dr. Per Hyltoft Petersen, Noklus (co-supervisor)

The main research output from this project is the improved statistical estimation of biological variation of analytes, which provides insights into the natural variability of laboratory results. The key papers are item 1-2. in section 3.

b. "What is normal for me? Individualizing measures for biological variations for improved diagnostics and monitoring". Project funded by Helse Vest RHF, period 2018-2020. Key researchers:
    a. Professor and leader of Noklus Sverre Sandberg
    b. Post.doc. Thomas Røraas, Noklus
    c. Professor Bård Støve, Department of Mathematics, UiB
    d. Dr. Aasne K. Aarsand, Noklus and Department of Medical Biochemistry and Pharmacology, Haukeland University Hospital, Bergen, Norway

This project is a continuation of the first project, focusing on biological variation estimates, in this case proposing individualized measures, utilizing a Bayesian approach. The key papers are item 3-4. in section 3.

c. "Commutability of external quality assessment (EQA)-materials and statistical methods of evaluation", PhD research position and research time funded by Noklus. Project period 2021-exp. 2026. Key researchers:
    a. Professor and leader of Noklus Sverre Sandberg (co-supervisor)
    b. PhD-student Pernille K. Fauskanger, Noklus and Department of Mathematics, UiB (enrolled in the PhD-program in Statistics, and obtained a MSc in Statistics from UiB 2020 with Støve, Røraas and Sandberg as supervisors)
    c. Professor Bård Støve, Department of Mathematics, UiB (main supervisor)
    d. Dr. Anne Stavelin, Noklus. (co-supervisor)

In addition to the above researchers, the project is part of an international project on commutability with the following additional participants: , Jesper V Johansen (DK), Thomas Keller(DE), Jeffrey Budd (US), Neil Greenberg (US), Robert Rej (US), Mauro Panteghini (IT), Vincent Delatour (FR), Ferruccio Ceriotti (IT), Liesbet Deprez (BE), Johanna E Camara (US), Finlay MacKenzie (UK), Alicia N Lyle, Eline van der Hagen (NL), Chris Burns (US), W Greg Miller (US). Although a still on-going project, the main research findings so far is the establishment of a new method to assess commutability for EQA-material. In particular, the research has provided recommendations for how to establish a criterion for acceptable commutability, where the key papers are item 5-6. in section 3. The main research for these papers were undertaken in 2021 and 2022.

3. References to the research (max 6 references)

Below is references to a selected output of the research which forms the basis for the impact case. *Clinical Chemistry* is a high-impact peer review journal, latest impact factor: 9.3, level 2 in the Norwegian Register for Scientific Journals.

1. Røraas T., Støve B., Sandberg S. & Petersen P.H. (2016), Biological Variation: The Effect of Different Distributions on Estimated Within-Person Variation and Reference Change Values, *Clinical Chemistry*, 62(5), 725-736. https://doi.org/10.1373/clinchem.2015.252296 [Paper listed in table 1.3 "Best percentile value papers" in the bibliometric summary of the administrative unit]

2. Røraas, T., Støve, B., Petersen, P.H. & Sandberg, S. (2017). Biological variation: Evaluation of methods for constructing confidence intervals for estimates of within-person biological

variation for different distributions of the within-person effect*, Clinica Chimica Acta*, 468, 166-173. https://doi.org/10.1016/j.cca.2017.02.021

3. Røraas, T., Sandberg, S., Aarsand, A.K. & Støve, B. (2019). A Bayesian approach to biological variation analysis, *Clinical Chemistry*, 65(8), p. 995-1005. https://doi.org/10.1373/clinchem.2018.300145

4. Aasne K Aarsand, Ann Helen Kristoffersen, Sverre Sandberg, Bård Støve, Abdurrahman Coşkun, Pilar Fernandez-Calle, Jorge Díaz-Garzón, Elena Guerra, Ferruccio Ceriotti, Niels Jonker, Thomas Røraas, Anna Carobene (2021). The European Biological Variation Study (EuBIVAS): Biological Variation Data for Coagulation Markers Estimated by a Bayesian Model, *Clinical Chemistry*, 67(9), 1259-1270. https://doi.org/10.1093/clinchem/hvab100

5. Sverre Sandberg, Pernille Fauskanger, Jesper V Johansen, Thomas Keller, Jeffrey Budd, Neil Greenberg, Robert Rej, Mauro Panteghini, Vincent Delatour, Ferruccio Ceriotti, Liesbet Deprez, Johanna E Camara, Finlay MacKenzie, Alicia N Lyle, Eline van der Hagen, Chris Burns, W Greg Miller, for the IFCC Working Group on Commutability in Metrological Traceability (2023). Recommendations for Setting a Criterion and Assessing Commutability of Sample Materials Used in External Quality Assessment/Proficiency Testing Schemes, *Clinical Chemistry*, 69(11), 1227-1237. https://doi.org/10.1093/clinchem/hvad135

6. Fauskanger, P., Sandberg, S., Johansen, J., Keller, T. Budd, J., Miller, W.G., Stavelin, A., Delatour, V., Panteghini, M. & Støve B. (2023). Quantification of difference in non-selectivity between in vitro diagnostic medical devices. Under review, *Statistics in Biopharmaceutical Research*. Available upon request.

4. Details of the impact (indicative maximum 750 words)

Statistics plays a crucial role in laboratory medicine and clinical chemistry, impacting various aspects of the fields. The main impact from the research in this particular case, is how better use of statistical methods and how more advanced statistical methods, previously not used in this area, can a) **improve the validity and accuracy of estimates of biological variation**, and b) **better assess commutability of sample materials used in external quality assessment** (EQA). Hence, this has affected how laboratories and EQA-organizations execute their work, not only in Norway, but also worldwide.

In the following, a more detail presentation of these two main impacts will be given. Again, recall that the research has been a collaborative effort between Noklus, Dept. of Mathematics, UiB, who has provided expert input regarding the application of different statistical methods, and to international partners where Thomas Røraas and Pernille Fauskanger have participated as expert consultants (i.e. WG-Biological variation in the European Federation of Clinical Chemistry and Laboratory Medicine (EFLM) and WG-Commutability in the the International Federation of Clinical Chemistry and Laboratory Medicine (IFCC).

Regarding impact a): the biological variation (BV) of an analyte (i.e. how much an analyte varies within the human body in a single person or how much an analyte varies between persons), e.g. cholesterol or glucose, is an important factor when establishing what can be considered normal or abnormal results of laboratory tests or when evaluating what changes

between repeated measurements indicate a change in the patient's clinical condition. In particular, when monitoring patients, it is important to know the biological variation of the analyte in question to be able to judge whether a change in a laboratory test is caused by the disease or can be explained by the natural biological variation. Other BV applications include using BV data for setting analytical performance specifications (to calculate how good analytical quality laboratories need to have), to calculate reference change values, to define the index of individuality and to establish personalized reference intervals. The research conducted in projects i) and ii) introduced in section 2, has improved the statistical modelling to calculate BV estimates. In particular, the CV-ANOVA method introduced in paper 1 (Røraas et al (2016)), has been widely used, and the Bayesian approach of calculating BV estimates (paper 2, Røraas et al (2017), has also attracted considerable interest from practitioners. Computer code for practitioners has been provided (see reference 3, Section 5).

Hence, the beneficiaries of the impact of the research, is Noklus itself (reference 1, Section 5), and EQA-providers, medical laboratories across the world, and clinical guideline developers who are now able to perform the statistical analysis in a better way, regarding studies of BV. Consequently, as reliable estimates of BV play a vital role in disease diagnosis and monitoring of patients, ultimately this will contribute to **improved patient outcomes**. The impact thus happened directly after the publications, 2017-2018, regarding the use of the statistical methods.

Moreover, the two papers mentioned above, and others not reported, form parts of the basis for the "Standard for evaluating BV publications" (reference 4-6, Section 5) and the corresponding BV database established by the European Federation of Clinical Chemistry and Laboratory Medicine (EFLM) (reference 7, Section 5). This database of BV data is available for laboratories worldwide.

The importance of this work is also underlined by the fact that in 2022 a whole special issue on biological variation of the well esteemed international journal "Clinical Chemistry and Laboratory Medicine" was dedicated to Thomas Røraas (Clin Chem Lab Med 2022; 60(4): 465–468) (reference 10, Section 5).

Regarding impact b): Ensuring the commutability of external quality control materials (EQAMs) with clinical samples is crucial. Commutability implies that these materials should exhibit behavior similar to clinical samples when analyzed with end-user clinical laboratory in vitro diagnostic medical devices (IVD-MDs). Employing commutable EQAMs allows for the assessment of metrological traceability and/or equivalence of results across various types of instruments. The research conducted in project iii) has so far provided an improved method of assessing commutability (paper 6), and furthermore a paper (paper 5), that offers guidance on setting criteria for acceptable commutability in EQAMs. The recommendation paper 5., has been undertaken in conjunction with the IFCC (reference 8, Section 5), and provides computer code for practical use (reference 2, Section 5).

Again, the beneficiaries in this case are Noklus, and other EQA-providers worldwide. Hence, the impact of this research has contributed to the reliability of laboratory data and enhances the overall quality assurance process of EQA-providers. Furthermore, some clinical chemistry tests can be performed at or near the patient's bedside, known as point-of-care-testing (POCT), providing rapid results for immediate clinical decision-making. POCT is particularly useful in emergency situations or in settings where timely results are critical. The improved method for commutability and recommendations are also valid for in-vitro medical devices for POCT (reference 9, Section 5), and as there is evidence that quality assurance improves the quality of POCT measurements. Consequently, the main impact of the research is again

ultimately, **improved patient outcomes**. The results from these papers resulted in that Noklus was selected as partner in the EU Horizon 2020 project entitled "Comet" on metrological traceability. The project was awarded funding in the Autumn 2023. It will then be important to employ more people from the Department of Mathematics, UiB, for further research in collaboration with Noklus.

5. Sources to corroborate the impact (max 10 references)

1. Introduction to Noklus: https://www.noklus.no/en/the-norwegian-organization-for-quality-improvement-of-laboratory-examinations/
2. Computer code for practitioners I: https://www.noklus.no/en/a-practical-tool-for-commutability-evaluation-of-external-quality-assessment-material-under-construction/
3. Computer code for practitioners II: https://gitlab.com/thoror/bayesian_bv_paper
4. Standard for evaluating studies on biological variation: https://academic.oup.com/clinchem/article/64/3/501/5608807
5. Prize from EFLM (European Federation of Laboratory Medicine and Clinical Chemistry) to researchers at Noklus: https://tidsskriftet.no/2019/12/fra-andre-tidsskrifter/prestisjetung-pris-forskning-pa-biologisk-variasjon
6. Biological variation – recent survey paper referring to our research: https://doi.org/10.1515/cclm-2022-1255
7. EFLM Biological Variation Database: EFLM Biological Variation
8. IFCC (International Federation of Clinical Chemistry and Laboratory Medicine) Working Group: Commutability in Metrological Traceability (WG-CMT) - IFCC
9. Survey of quality assurance of point-of-care testing: https://doi.org/10.1080/10408363.2023.2262029
10. Special issue on Biological variation dedicated to Thomas Røraas - Clin Chem Lab Med 2022; 60(4). https://doi.org/10.1515/cclm-2022-0086

University of Bergen, Department of Mathematics [3]

Institution: University of Bergen
Administrative unit: Department of Mathematics
Title of case study: Arkimedes labyrint
Period when the underpinning research was undertaken: 2015-2018
Period when staff involved in the underpinning research were employed by the submitting institution: 1991-present
Period when the impact occurred: 2018

1. Summary of the impact: Mathematical outreach towards schools and society. Two different activities:

• The construction of a mathematical maze named "Arkimedes Labyrint" in the botanical garden of Bergen.

• The Mathematics Circle, an educational program for high school students aimed at recruiting talents.

Both activities were led by Prof. Hans Munthe-Kaas. Coverage in various media such as Science Magazine, national and international newspapers.

2. Underpinning research: The *Mathematics Circle,* an advanced honors level undergraduate course for select numbers of high schoolers, was organised at DoM four years (2015-2018). About 20 highly motivated high-school students met once a week, two semesters, to study mathematics on beginning university level. The main topics were in first half: group theory, symmetries, theory of tessellations, wallpaper groups and spherical tessellations. In the second half applications of groups in coding theory and cryptography. The students took an exam in the end. As an example, we proved the classical classification of 7 frieze groups and 17 wallpaper groups, based on the 'Magic Formula' of John H. Conway. Literature: Conway "Symmetry of things" + compendium written by Munthe-Kaas. Many of the students continued to study mathematics, at UIB, NTNU and Cambridge, among other.

In 2016, UiB planned an upgrade of the Botanical Garden outside Bergen and wanted the construction of a Maze. Professor Munthe-Kaas joined a project group consisting of a botanist, a landscape architect, an artist, and a mathematician. The design of the labyrinth (maze) is based on mathematical symmetries, as well as forms found in nature, such as Archimedean spirals, an underlying honeycomb lattice and crystallographic symmetries (wallpaper group). The basic design criteria:

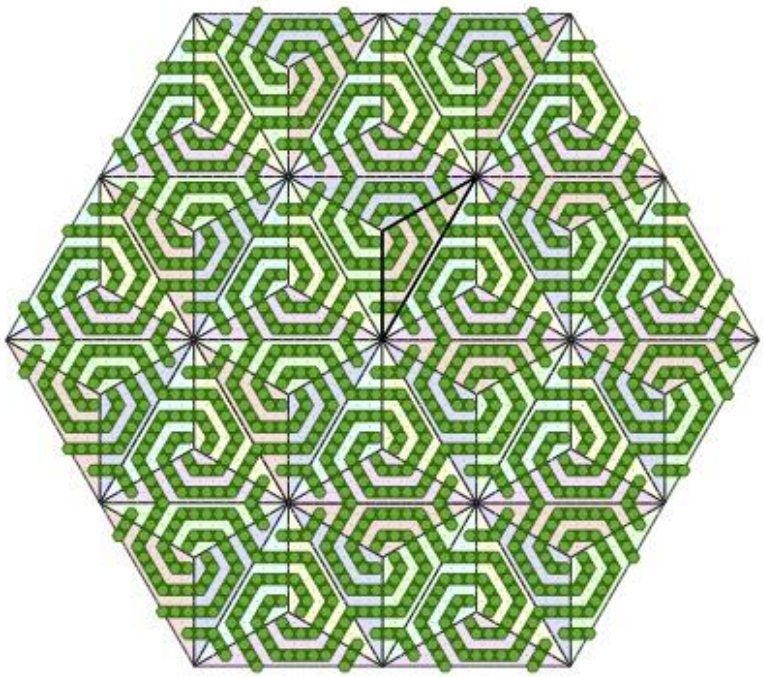
- Underlying structure hexagonal lattice.
- Rotational symmetries of order at least 3 (for spirals).
- Reflection symmetry (for spirals in both directions).

can be fulfilled only for one of the 17 wallpaper groups, (3*3) in Conway orbifold notation. The finished maze covers an area of 800 square meters. It consists of 1234 yews in a hexagonal array.

The "Arkimedes Labyrint" (named from the spirals) has become a popular site for outreach activities at UIB, with various activities of mathematical flavour over the last years. In 2018 Abel Prize laureate Karen Uhlenbeck visited the site where we also held mathematical activities for school children, as the annual public outreach program at the Abel prize week.

The "Arkimedes Labyrint" and the visit of Abel laureate Karen Uhlenbeck was covered in several media, such as the local newspapers in Bergen (Bergensavisen), Science Magazine, a

Spanish newspaper, a Korean newspaper, and a news notice in AMS (references below). Arkimedes Labyrint and the activities of the Mathematic Circle have been presented in various public lectures.



3. References to the research

• Science Magazine, Oct. 9, 2018: Dizzying labyrinth will host next year's party math's Nobel prize
• AMS: https://www.ams.org/news?news_id=4637
• Korea: https://mdl.dongascience.com/magazine/view/M201811N008
• Mathematics news-blog: https://simanaitissays.com/2018/10/24/on-norwegians-a-maze-and-a-party-for-maths-nobel/
• Bergensavisen: https://www.ba.no/nyheter/ytrebygda/kulturvern/bergens-nye-attraksjon/s/5-8-889582
• The Mathematics Circle: https://www.uib.no/math/97368/matematikksirkelen (Norwegian)

4. Details of the impact

The impact of these projects is two-fold:

- Recruitment of students to mathematics.
- Outreach to society conveying the beauty of mathematics, and relations between mathematics and art.

5. Sources to corroborate the impact

Student recruitment:
The super student Birk is the man of the future (Norwegian)
They start higher education "before time": - We are probably seen as a bit nerdy (Norwegian)
Marius (16) studies at UiB (Norwegian)

Other sources: See under point 3.

University of Oslo - Department of Mathematics impact case 1

Institution: University of Oslo
Administrative unit: Department of Mathematics
Title of case study: BigInsight – Centre for Research-based Innovation
Period when the underpinning research was undertaken: 2015-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2015-2022
Period when the impact occurred: 2017-2022

1. Summary of the impact

In the BigInsight project, our researchers were collaborating with various partners from industry. Several results, methods and prototype codes developed by our PhD students and faculty inside BigInsight, have been implemented in the partner businesses, and by such they have made economic impact, but also societal and safety critical impact. We have chosen some examples from BigInsight, related to banking and fraud detection, and maritime industry. The beneficiaries of our research are in these examples the main Norwegian bank DNB, the maritime section of the certification company DNV (Veritas) and the marine technology company ABB.

2. Underpinning research

The persons in our unit involved in the reported BigInsight impact cases are:
Banking, fraud: PhD students Håvard Kvamme (employed at the Department of Mathematics 2016 – 2019) and Simon Brant (2018 - 2021), faculty Ingrid Hobæk Haff
Maritime industry: PhD students Martin Tveten (2017 - 2020), Emanuele Gramuglia (2017 - 2020) and Clara Salucci (2019 - 2023), Post doc Azzeddine Bakdi (2018 - 2021), faculty Riccardo De Bin, Ingrid Glad, Geir Storvik.

The common ground for these research projects is that they have been funded and carried out in the BigInsight centre and are motivated by complex, large data sets and problems that the partner institutions brought into BigInsight. Through the integration of cutting-edge statistical methods, advanced machine learning techniques, and invaluable domain expertise provided by our industrial partners, we have pioneered innovative solutions. These groundbreaking methods, distinguished by their novelty and originality, have not only garnered significant publication recognition but have also been seamlessly integrated into our partners' production lines, showcasing their practical implementation and effectiveness. The papers described are listed in box 3 below.

Paper 1) predicts mortgage default by applying convolutional neural networks to consumer transaction data. By combining CNNs with a random forests classifier, the predictions become surprisingly accurate and hence applicable in practice. This was a timely application of convolutional neural nets to time series data.
Paper 2) improves on the binary, heavily unbalanced classification problem in fraud detection, by introducing a novel loss function and using penalised methods and boosting, for estimating the probability of fraud. These two papers have had impact among others for the main Norwegian bank DNB, see below.

The next four papers are all connected to our collaboration with DNV and ABB. Log files containing textual messages with associated time stamps, are generated by many technologies and systems for condition monitoring.

Paper 3) proposes a clustering technique which provides a tool to discover and identify patterns or macrolevel events in such categorical time series, using a Bayesian approach and reversible jump MCMC. Such log messages are common in marine equipment and the method is implemented at ABB, see below.
Paper 4) is also about condition monitoring, presenting a novel, scalable approach to detecting anomalous mean structure in a subset of correlated multivariate time series. A computationally efficient approximation of the maximum likelihood solution to the resulting modelling framework is developed, along with a new dynamic programming algorithm for solving the resulting binary quadratic programme when the precision matrix of the time series at any given time point is banded.
Paper 5) is the first paper of two that investigate battery state of health monitoring based on sensor data. A Multivariable Fractional Polynomial regression model is applied to data under dynamic operating conditions. The method is computationally very efficient and interpretable and compares well with a more complicated machine learning model.
Paper 6) is the first paper of two that formulates a completely new way of creating realistic test beds for the steering algorithms of autonomous ships. Using historical AIS data that tracks the movements of all traffic at sea, ship registries, weather data, digital maps, and ship collision avoidance rules, this data science project presents algorithms that quantify collision and grounding risks in short time windows ahead and create a large data base of scenarios of known difficulties in any geographical area. This database is used to draw test situations in which autonomy algorithms can be tested and compared to historical human solutions. It is implemented at DNV, se below.

3. References to the research

Authors employed at Dept. of Mathematics indicated in bold face.

1) **H Kvamme**, N Sellereite, K Aas, S Sjursen (2018) Predicting mortgage default using convolutional neural networks *Expert Systems with Applications* 102, 207-217
2) **SB Brant** & **IH Haff** (2022) The fraud loss for selecting the model complexity in fraud detection *Journal of Applied Statistics*. ISSN 0266-4763.
3) **E Gramuglia**, **G Storvik**, **M Stakkeland** (2021) Clustering and automatic labelling within time series of categorical observations—with an application to marine log messages *Journal of the Royal Statistical Society Series C: Applied Statistics*
4) **M Tveten**, IA Eckley, P Fearnhead (2022) Scalable changepoint and anomaly detection in cross-correlated data with an application to condition monitoring *Annals of Applied Statistics* 16 (2), 721-743
5) **CB Salucci**, **A Bakdi**, **IK Glad**, **E Vanem**, **R De Bin** (2022) Multivariable fractional polynomials for lithium-ion batteries degradation models under dynamic conditions *Journal of Energy Storage* 52, 104903
6) **A Bakdi**, **IK Glad**, **E Vanem**, Ø Engelhardtsen (2019) AIS-based multiple vessel collision and grounding risk identification based on adaptive safety domain *Journal of Marine Science and Engineering* 8 (1), 5

4. Details of the impact

The links to media references indicated with letters in the text, are listed in box 5 below.

Impact for DNB and their costumers:

As described in the news article a) about paper 1), this was the first time DNB used machine learning to predict mortgage default. The impact is societal for bank customers:

<<"*We will be able to say yes to certain customers we say no to today. And for those we say no to, it will be good customer advice, so they do not accumulate a debt they cannot service," says Tron Even Skyberg, Division Director and Head of Risk Quantification at DNB*>> (translated from a) with UiOGPT).

Also, the method (and its further development later) has economic impact for DNB:

<<*According to DNB, the new method is slightly better than the current strategy for identifying high-risk customers, and when the methods are combined, it can likely significantly reduce the bank's losses. "The worst percent of the portfolio ranked by this system accounts for half of the defaults," says Skyberg.*>> (translated from a) with UiOGPT).

DNB has also benefitted from our work on fraud detection, applied to detection of money laundry crime. As explained in the interview b) fighting financial crime has enormous impact for the society at large. Fraud detection is mathematically difficult, as explained by Ingrid Hobæk Haff in b):

<< *One of the many mathematical intricacies is unbalanced datasets.… Another tricky problem for the mathematicians is not only the large quantity of data, but also the many dependencies between the different data.*>>

The research that was later published in paper 2) solved these problems.

As stated by data scientist Lars Erik Bolstad at DNB in the interview c), DNB also has economic benefits from these methods:

<<*"So far, the test datasets have yielded promising results. Now, we are automating previously manual and time-consuming processes. This will allow us to uncover suspicious cases much faster and easier. The accuracy will also increase," says Lars Erik Bolstad.*>> (translated from c) with UiOGPT).

Impact for DNV and ABB:
In BigInsight, we have also worked with statistical and machine learning research motivated by problems and data from maritime industry, especially connected to new approaches to safety surveillance, condition monitoring and performance monitoring of vessels or equipment based on large arrays of sensors.

Examples of impact at DNV and ABB include research on new methods for automatic detection of developing faults or anomalies based on sensor and ship log data. Papers 3) and 4) are examples of such research that has been implemented in these two partner companies. PhD student Gramuglia was hired for a period at ABB to implement the method of paper 3) in their equipment. The work in paper 4) has been applied to subsea pump data. In the interview d) with ABB researcher Morten Stakkeland, he comments on the impact of the collaboration:

<< *One company that has adopted this new way of thinking is the international industrial group ABB. They work closely with statisticians at the University of Oslo to enable shipping companies to save millions on more optimal operations and improve*

ship safety.... "Instead of sending inspectors on board ships, we can rather use statistical methods to monitor all the data for changes, such as when the engine is about to overheat or break down. This automatic data monitoring should be able to provide warnings about incidents before they happen", says Morten Stakkeland>>

The interview also comments on work we have performed on battery health monitoring (f.ex. for electric vessels), as published in several papers, represented by paper 5).
Through development of monitoring methods based on sensor data, the electric vessels don´t need to be taken out of operation for battery controls. In d) it is stated that

<< "This is lost uptime. We look at how it is possible to use statistics to evaluate the batteries. This will save shipowners a lot of money", says Morten Stakkeland. One of the big points is maintenance only when needed, rather than at fixed intervals. "Shipowners could potentially save millions of kroner per ship", Stakkeland points out.>>

Another example of both economic and safety critical impact are a couple of papers on autonomous shipping, as in paper 6). The system has been implemented and is in operation/development at DNV in Trondheim. Bakdi travelled to Trondheim to help DNV implement the codes in their autonomy testing facilities there. In addition to testing algorithms, the system can be also be used for training such algorithms.

5. Sources to corroborate the impact

a) Interview with Håvard Kvamme and Tron Even Skyberg (DNB): **The robot grants you loans if it receives good vibrations from your account** (in Norwegian) published in *Dagens Næringsliv* (daily business newspaper) April 30th 2017 https://www.dn.no/privatokonomi/robotrevolusjonen/norsk-regnesentral/dnb-dnb/roboten-gir-lan-hvis-den-far-gode-vibrasjoner-fra-kontoen-din/2-1-74994

b) Interview with Ingrid Hobæk Haff: **Uncertain future for fraudsters**, published in *sciencenorway.no, Apollon* February 2019 https://www.sciencenorway.no/crime-forskningno-norway/uncertain-future-for-fraudsters/1553504

c) Interview with Ingrid Hobæk Haff and Lars Erik Bolstad (DNB): **DNB gets BigInsight (in Norwegian),** published in *Finans-fokus.no* April 4th 2019 https://www.finansfokus.no/2019/04/24/dnb-far-big-insight/

d) Interview with Ingrid Glad, Morten Stakkeland (ABB) and Erik Vanem (DNV): **Avoids ship disasters with advanced statistics**, published in *sciencenorway.no, Apollon, Ingeniørens Stemme, Forskning.no* February 2019 https://www.sciencenorway.no/forskningno-norway-statistics/avoids-ship-disasters-with-advanced-statistics/1553406

University of Oslo - Department of Mathematics impact case 2

Institution: University of Oslo
Administrative unit: Department of Mathematics
Title of case study: Ship-driven mini-tsunamis
Period when the underpinning research was undertaken: 2013, 2015-17, 2020
Period when staff involved in the underpinning research were employed by the submitting institution: 2013, 2015-17, 2020
Period when the impact occurred: 2016-17, 2022

1. Summary of the impact

I explained how the two big ships of *Color Line*, the world's biggest cruise-ferries with a car-deck, made fore-running mini-tsunamis of length 0.5 - 1 km, and amplitude of up to 1 m, causing erosion and hazard at several places along the shore of Oslofjorden, Norway, and how the liner could avoid making the waves, an effect not known before worldwide. The liner has changed sailing practice, and the waves are now avoided.

2. Underpinning research

Summer 2013: request from the Norwegian Broadcasting NRK: Can I explain 1) why wave disturbances can propagate upstream of the large ships of *Color Line*, and 2) why the waves are made only by the ships of *Color Line* and not other ships (lines) cruising along Oslofjorden? Oslofjorden is a leisure area used by approximately one quarter of the Norwegian population. The phenomenon was observed by canoers and the public and reported in radio summer show by Norwegian Broadcasting NRK. The waves came with a new erosion and hazard to people enjoying the fjord, modified the shore, damaged harbour constructions, marinas and other infrastructure.

Fantasy and *Magic* of *Color Line* were introduced in 2004 and 2007, respectively, to serve between Oslo and Kiel. Of displaced mass of 36 000 tonnes, approximately, they are the world's largest cruise ferries with a car-deck. The typical cruising speed is 10 m/s, much smaller than the typical long wave speed (tsunami speed) of the fjord is sqrt (g *h) =20 m/s (g=9.81 m/s2 acceleration of gravity, h=40 m water depth).

Summer 2013 journalist Torkild Jemterud of NRK took me to a spot were the phenomenon occurred, a narrow sound at Askholmene. I made a series of photos of the water level ahead of the passing ship, without observing any effect. I could not really view an upstream wave. However, at the very shallow beach, powerful disturbances came well before the classical ship waves. The cruising speed was well subcritical. I suspected the upstream effect at the beach might occur because of the changing depth along the ship's track. This was strongly reduced in the narrow sound. I had checked the sea-chart in advance. A video of the phenomenon at Askholmene was published on youtube.

Upstream solitons are made at criticial speed (ship speed = shallow water speed), a well known phenomenon, but this was noting like this. The low subcritical ship speed didn't match.

In autumn 2015 I eventually found time to analyse the potential upstream effect and made a research effort for presentation at the annual International Workshop on Water Waves and Floating bodies and test if it was anything in it. I modified a theory using Fourier transform formulation in 3D which I had myself derived (published as part of Clamond and Grue, JFM, 2001) and extended to variable depth in Fructus and Grue (JCP 2007). The ship was mimicked by a

moving surface pressure distribution. Rearranged a Fortran code to compute the effect of a depth change, like at at Askholmene, and got as result a forward propagating wave of a few cm. The amplitude increased according to the ship speed to power three. I took the wave period from the available youtube video from Askholmene.

In January 2016 I made a field study, on two different days, to two locations, Snarøya and Nesodden/Flaskebekk in Oslofjorden, where the waves were usually prominent, as suggested by journalist Torkild Jemterud. I recorded the wave periods - trough-to-peak-to trough-to-peak period and so on, for *Fantasy*, *Magic* and a smaller ship *Pearl Seaways* of *DFDS*, another liner. I was also met by several of the local people. They were very frustrated by the damages, with estimated costs of millions of NOK. I made a deal with them: "please give me all you have of documentation and I will give you formulas back". I got a series of photos from Tore Henning Larsen at Nesodden/Flaskebekk and used them to estimate the wave height in a small bay/harbor there, of approx. 1 m. A wave height of 1.4 m was measured in that harbour by owner E. Staff, using a folding rule. The measured wave periods increased by distance to where the waves were made, suggesting a linear, dispersive phenomenon.

***Magic* produces harbor tsunami. Photo: TH Larsen**

Model calculations of the phenomenon at Flaskebekk obtained fair agreement with measured period at the shore. The wave height grew with the ship speed to a power between 3 and 4. The wave effect was found to occur at sudden depth changes of magnitude comparable to the depth itself. Waves were made both when the depth was reduced or increased.

The material was presented at the 31st International Workshop on Water Waves and Floating Bodies, MI, USA, 3-6 April 2016. The audience responded that this is a new phenomenon not described anywhere before.

I wrote up the analysis for a paper to Journal of Fluid Mechanics, submitted August 2016, revised and published January 2017. The leadership of *Color Line* respects that publication.

In 2020 I published a paper with the detailed physical generation explanation: Moving along a flat bottom, the big ships, of shape like flat rafts, produces a down-flux of water at the bow. At a sudden, strongly reduced dept, the down-flux is reflected from the bottom, producing an elevation at the bow. Similarly at the stern, but the other way. And anti-symmetrically at a sudden depth increase. The fluxes are obtained directly from the mathematical equations. The effect is strong enough to produce upstream waves.

3. References to the research

Grue, J. (2016) Upstream waves at ships moving at low subcritical speed. 31st International Workshop on Water Waves and Floating Bodies,
Plymouth, MI, USA, 3-6 April 2016, Eds. Robert Beck and Kevin Maki, University of Michigan.

Grue, J. (2017) Ship generated mini-tsunamis. Journal of Fluid Mechanics, Volume 816, 10 April 2017, pp. 142 - 166 (fulltext version in institutional repository)

Grue, J. (2020) Mini-Tsunami Made by Ship Moving Across a Depth Change. Journal of Waterway, Port, Coastal, and Ocean Engineering
Volume 146, Issue 5

4. Details of the impact

Spring 2016. I communicated the international response back to the people at Flaskebekk, who organised a meeting with the leadership of *Color Line*. An intense meeting with the CEO of *Color Line Maritime* and one of the captains on *Magic* ended with two questions: *where are the waves made?* and *are the formulas of John Grue right?* The captain said he would develop a new track for his ship *Magic* that avoided the shoal Ildjernsflu at Flaskebekk. The CEO promised to reduce the speed of *Magic* and *Fantasy*. The new route of *Magic* from 2016 and onwards, does not produce the waves, as documented wave wave radar measurements at Flaskebekk, put up by Miros, a wave radar company, from 2019 and onwards.

The documentary by NRK mini-tsunami i Oslofjorden (radio documentary in Norwegian) published in september 2017 basically stopped the Liner. Journalists documented the hazard by interviews with public around the inner Oslofjord, referenced to my documentation published in J. Fluid Mech./Cambridge Univ. Press, and that was respected. The liner eventually developed a new sailing practice. They also reduced the speed.

In 2022 *Fantasy* adopted to the new route followed by *Magic* since 2016.

The type of waves are basically gone in inner Oslofjord.

5. Sources to corroborate the impact

(All in Norwegian)

Kiel-fergen lager tsunamier i Oslofjorden forskning.no 26 Oct 2016

Tsunamien i Oslofjorden nrk.no 30 Sept 2017

Vil unngå tsunamibølger - senker farten nrk.no 1 Nov 2017

Endelig: Color Line senker farten forbi Nesodden amta.no 1 Nov 2017

Radar skal kontrollere "Oslofjord-tsunamien" nrk.no 29 Mar 2019

University of Oslo - Department of Mathematics impact case 3

Institution: University of Oslo
Administrative unit: Department of Mathematics
Title of case study: Sequential Monte Carlo methods for Covid-19 analysis
Period when the underpinning research was undertaken: 2020-2023
Period when staff involved in the underpinning research were employed by the submitting institution: 2020-2023
Period when the impact occurred: 2020-2023

1. Summary of the impact

The Covid-19 pandemic has required most countries to implement complex sequences of non-pharmaceutical interventions, with the aim of controlling the transmission of the virus in the population. To be able to take rapid decisions, a detailed understanding of the current situation is necessary. Estimates of time-varying, instantaneous reproduction numbers represent a way to quantify the viral transmission in real time. Such estimates were based on daily measures of confirmed positive tests as well as the number of hospitalizations due to Covid-19. Weekly reports from the Norwegian Institute of Public Health (NIPH) included such estimates and provided evidence-based situational awareness and forecasts for the decision makers.

2. Underpinning research

In the beginning of the Covid-19 pandemic, the Norwegian Institute of Public Health (NIPH) put together a modelling team for providing knowledge-based information about the spread of the disease. A compartmental (SIR-type) model combined with Approximate Bayesian Computing (ABC) algorithms were implemented in the early stage of the disease. Important ingredients of the model were to utilize mobility data provided by the largest Norwegian telecom company, integration of different data sources and a robust procedure handling new data every week. The ABC algorithm had several challenges, making the need for alternatives. In May 2020, Storvik was invited to be part of the modelling group with a specific task of implementing a Sequential Monte Carlo (SMC) algorithm for performing inference. SMC algorithms had so far been very little used within infectious diseases problems and not at the extent considered here. After an intense implementation period, the algorithm was put into the workflow and has weekly produced results for the weekly reports produced by NIPH.

Instantaneous reproduction numbers are often defined through a mathematical compartmental model of the epidemic, like a stochastic SEIR model, whose parameters must be estimated from multiple time series of epidemiological data. Because of very high dimensional parameter spaces (partly due to the stochasticity in the spread models) and incomplete and delayed data, inference is very challenging. Formulating the model as a state-space model allows for the use of sequential Monte Carlo algorithms, which further allow to estimate a daily-varying reproduction number for the Covid-19 epidemic in Norway with sufficient precision, based on daily hospitalization and positive test incidences. The method has been in regular use in Norway during the pandemics and appears to be a powerful instrument for epidemic monitoring and management.

The development of models and inferential algorithms have been performed through a close collaboration between the modelling group at NIPH, Arnoldo Frigessi at the Institute of Medical Sciences at UiO, Solveig Engebretsen at the Norwegian Computing Center and Geir Storvik at Department of Mathematics, UiO. The works has been performed from March 2020. Inference is still performed at a weekly basis. Alfonso Diz-Lois Palomares, who during the pandemic worked within the modelling group at NIPH has now started in a PhD position, supervised by Storvik, for further development of inference methods applicable for many other infectious diseases.

3. References to the research

- Storvik et al (2023): A sequential Monte Carlo approach to estimate a time-varying reproduction number in infectious disease models: the Covid-19 case. JRSSA 186 (4) 616-632. Discussion paper presented for the Royal Statistical Society June 2022.
- Engebretsen et al (2023): A real-time regional model for COVID-19: Probabilistic situational awareness and forecasting. PLOS Computational Biology, 9 (1).

The second paper did not include personnel from Dept of Mathematics but do together with the first paper describe the main model and inference research performed with respect to estimation of reproduction numbers.

4. Details of the impact

During the pandemic, many decisions had to be made with respect to different types of interventions. The weekly reports from NIPH were important inputs to the decision makers with respect to these decisions. Camilla Stoltenberg, who was the head of NIPH during the pandemic, has clearly stated that the mathematical modelling and statistical inference work performed during this period was essential for the knowledge-based information that NIPH could provide towards the Norwegian Directorate of Health and the government. In particular, the collaboration with researchers at the University of Oslo has been highlighted.

The results of the research were disseminated through the weekly reports from NIPH. These reports were also made open for public, giving the society abilities to comment and criticise all aspects of the work. Newspapers used these reports constantly during the pandemic.

5. Sources to corroborate the impact

- FHI COVID-19 modelling team (2022): Situational awareness and forecasting for Norway. Report from NIPH at week 2, 18 January 2022. Such reports were produced weekly where the estimates of daily reproduction numbers were part of the reports.
- De Blasio (2023): Coronavirus modelling at the NIPH. Description of the model first published at 2020 and continuously updated during the pandemic.

University of Oslo - Department of Mathematics impact case 4

Institution: University of Oslo
Administrative unit: Department of Mathematics and others
Title of case study: The biomechanics of sleep
Period when the underpinning research was undertaken: 2016-2023
Period when staff involved in the underpinning research were employed by the submitting institution: 2016-2023
Period when the impact occurred: 2021 - 2023

1. Summary of the impact

We have formed an interdisciplinary research environment focusing on mathematical modelling of important topics in neuroscience, which is at the frontier of science both in terms of neuroscience, imaging and computational models. At the heart of the research is multi-physics fluid dynamics mechanisms that clears metabolic waste from our brains as we sleep and how the dynamics change in dementia diseases.
In a series of papers, with advanced computational modelling we have demonstrated that clearance is affected by sleep and disease with image based modelling.

The research is a close collaboration with Oslo University Hospital, Faculty of Medicine, UiO and Simula Research Laboratory.

2. Underpinning research

Mathematics and scientific computing has played a pivotal role in this work.
First, by providing a quantitative image analysis of novel techniques and hundreds of patients where we have shown that the clearance process is different in awake and sleep [1] and that it is reduced in dementia diseases [2]. Furthermore, we have shown that tracers and potentially drugs access basically every part of the brain during a period of 48 hours when delivered through the cerebrospinal fluid. The novel imaging is now an integral part of the clinical assessment of at the hospital and already some of our joint papers on the subject are highly cited.
Secondly, by scrutinous and advanced mathematical modelling we have both verified and falsified various mechanistic theories that have been proposed to explained the clearance that occurs during sleep, theories that are still very much under debate in this blooming field. First, in 2017 [3], we demonstrated that extra-cellular diffusion with the brain is likely more potent driver of clearance than pressure driven convection as originally proposed. The finding, which is still the most advanced model until this day involved a detailed geometrical reconstruction of a 5 micron cube of the brain matter of a rat in terms of a finite element mesh with hundreds of millions of cells and the corresponding fluid flow through this model. The finding has stirred the neuroscience community for years and is still debated.

Furthermore, from a mathematical perspective, the proposed mechanisms of brain clearance have initiated a foundational effort on the well-posedness and stability of multi-physics problems in general. In detail the clearance system of our brain consists of interacting viscous and porous flows in elastic media. As such a dozen paper in high-profile mathematical journals from MI together with Simula Research Laboratory hints towards a general foundation for the singular perturbation problems arising in multi-physics settings where solutions of different regularity meet at common interfaces causing parameter dependent singular pertubations [4]. Alongside advanced numerical algorithms we have also developed high performance, open source software tools for subject specific assessment of neurodegenerative diseases, resulting in a book [5] that describes the methodology and software tools and which hopefully will make the framework available to wide-spread usage.

3. References to the research

[1] Eide PK, Vinje V, Pripp AH, **Mardal KA**, Ringstad G. Sleep deprivation impairs molecular clearance from the human brain. Brain. 2021 Mar 1;144(3):863-74.

[2] Ringstad G, **Valnes LM**, Dale AM, Pripp AH, Vatnehol SA, Emblem KE, **Mardal KA**, Eide PK. Brain-wide glymphatic enhancement and clearance in humans assessed with MRI. JCI insight. 2018 Jul 7;3(13).

[3] Holter KE, Kehlet B, Devor A, Sejnowski TJ, Dale AM, Omholt SW, Ottersen OP, Nagelhus EA, **Mardal KA**, Pettersen KH. Interstitial solute transport in 3D reconstructed neuropil occurs by diffusion rather than bulk flow. Proceedings of the National Academy of Sciences. 2017 Sep 12;114(37):9894-9.

[4] Budiša A, Hu X, Kuchta M, **Mardal KA**, Zikatanov LT. HAZniCS–software components for multiphysics problems. ACM Transactions on Mathematical Software. 2023 Dec 15;49(4):1-23.

[5] **Mardal KA**, Rognes ME, Thompson TB, Valnes LM. Mathematical modeling of the human brain: from magnetic resonance images to finite element simulation. Springer Nature; 2022.

4. Details of the impact

On the other hand, we showed in 2023 [7], by imaging based modelling and partial differential equation based parameter identification that by transport is faster than our previous predictions in [3] and that as such there are some unknown mechanisms at play. A reconciling finding is perhaps our 2023 demonstration that the slow vascular pulsations during sleep is 10x that caused by cardiac pulsation and as such these pulsations may be main drivers of clearance [6].

Our findings has resulted as mentioned in top tier journal publications and has resulted in various reports in mass media such as VG. Furthermore, the investigations is now extended to new patient groups such as brain cancer, Parkinson and stroke, see for instance the GRIP study: https://www.oslo-universitetssykehus.no/kliniske-studier/det-glymfatiske-systems-rolle-i-parkinsons-sykdom-grip-studien.

On the more mathematical aspects, our mathematical and software frameworks are being used actively at several leading institutions like University of Oxford, Politecnico Milano, University of Texas at Austin. And as we have published more than a dozen papers on the mathematical aspects of multi-physics problems, we are now in a position to lead foundation analysis on multi-physics problems arising in biomechanics.

In conclusion, while the back-bone of the current research is basic research on challenging neuroscience topics and complex multi-physics applications, we have formed an efficient and productive research environment with real international impact within neuroscience and which here in Oslo, at the moment, is changing clinical practice hopefully with better tools for understanding the overwhelming burden of dementia. While the steps towards a cure may be modest, the investigations are novel and impactful.

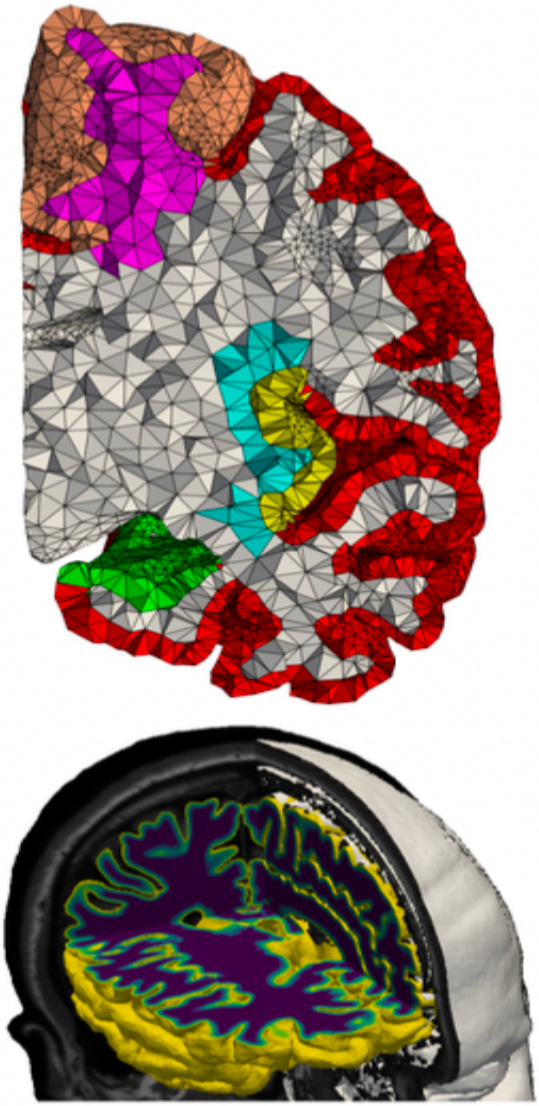


Figure 1: Top: Mesh and subdomain markers for subject specific simulations of brain mechanics. Bottom: Diffusion simulation based on MRI images. Both taken from [5].

5. Sources to corroborate the impact

[6] Vinje V, Zapf B, Ringstad G, Eide PK, Rognes ME, Mardal KA. Human brain solute transport quantified by glymphatic MRI-informed biophysics during sleep and sleep deprivation. Fluids and Barriers of the CNS, 2023.

[7] Bojarskaite L, Vallet A, Bjørnstad DM, Gullestad Binder KM, Cunen C, Heuser K, Kuchta M, Mardal KA, Enger R. Sleep cycle-dependent vascular dynamics in male mice and the predicted effects on perivascular cerebrospinal fluid flow and solute transport. Nature communications. 2023 Feb 20;14(1):953.

Pusten kan påvirke rensing av hjernen Forskning.no 15 Jul 2019 (in Norwegian)
Ny, norsk forskning: Slik påvirkes hjernen av for lite søvn VG, 20 Apr 2021 (in Norwegian)
Forskning om hjernen og søvn: Kan hindre utvikling av Alzheimers VG, 27 Mar 2023 (in Norwegian)
A Beneficial Type of "Brainwashing" Happens While You Sleep Technology Networks, 31 Mar 2023

University of Oslo, Department of Informatics [Impact case #3]

Institution: University of Oslo
Administrative unit: Department of Informatics (IFI)
Title of case study: Machine learning for improved cardiac ultrasound
Period when the underpinning research was undertaken: 2013-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2013-2022
Period when the impact occurred: 2014-2022

1 Summary of the impact

Echocardiography is the primary imaging tool for cardiologists to assess cardiac function and structures. Machine learning techniques to provide automatic measurements or interpretations from ultrasound imaging can contribute to efficient examinations and reduce inter-observer variability. By providing new machine learning tools for several tasks like suppressing noise, detecting cardiac valve events, mitral annulus segmentation we have contributed to more efficient examinations. In cooperation with GE Healthcare, these methods have been taken from published papers to results implemented in commercial ultrasound scanners deployed worldwide.

2 Underpinning research

Over the period 2013-2022, the DSB-group at IFI has partnered in a series of joint projects on image analysis and machine learning with GE Healthcare and their research department in Norway. This started with 3DUS-project (2013-16), and continued with INCUS (2016-201), the INIUS innovation project (2017-21), the EchoAI project (2020-2023) and the SFI Visual Intelligence from 2020. Over this decade, the following researchers have contributed to the impact:

- Anne Solberg (Professor, UiO)
- Eigil Samset (adjunct professor, UiO)
- Hani Nozari Mirar (phd. candidate to 2020)
- Sten Road Snare (postdoc to 2016)
- Tollef Jahren (phd. candidate to 2022)
- Andrew Gilbert (phd. candidate to 2021)
- Børge Solli Andreassen (phd. candidate to 2022)
- Christiana Tiago (phd. candidate to 2022)
- Sarina Thomas (postdoc from 2021).

The impacts are related to better image quality and more efficient ultrasound scanning across a range of normal and difficult-to-scan individuals examined using cardiac ultrasound scanners. Mirar and Snare contributed to improved image quality in the initial years of cooperation between UiO and GE Healthcare. Jahren, Andreassen, Gilbert, Tiago, and Thomas have been central in applying deep learning to cardiac ultrasound. The contributions are discussed more in detail in the next sections. It is worth noting that in addition to the image analysis and machine learning research highlighted in the current impact case, additional research collaborations related to image reconstruction and signal processing are conducted between GE Healthcare and DSB through the Centre for Innovative Ultrasound Solutions (CIUS) SFI.

The phd. candidates have also contributed to implementing their methods into GE Healthcare systems, and some of the most significant methods are also implemented into ultrasound scanners, so they can be of benefit to future patients.

3. References to the research

Jahren, Tollef Struksnes; Steen, Erik Normann; Aase, Svein Arne & Solberg, Anne H Schistad (2020). Estimation of End-Diastole in Cardiac Spectral Doppler Using Deep Learning. IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control. ISSN 0885-3010. 67(12), s. 2605–2614. doi: 10.1109/TUFFC.2020.2995118.
Må legges I viten.

A. Gilbert, M. Marciniak, C. Rodero, P. Lamata, E. Samset and K. Mcleod, "Generating Synthetic Labeled Data From Existing Anatomical Models: An Example With Echocardiography Segmentation," in *IEEE Transactions on Medical Imaging*, vol. 40, no. 10, pp. 2783-2794, Oct. 2021, doi: 10.1109/TMI.2021.3051806. Fulltext:

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Andreassen, Børge Solli; Volgyes, David; Samset, Eigil & Solberg, Anne H Schistad (2022). Mitral Annulus Segmentation and Anatomical Orientation Detection in TEE Images Using Periodic 3D CNN. IEEE Access. ISSN 2169-3536. 10, s. 51472–51486. doi: 10.1109/ACCESS.2022.3174059. Fulltext: https://www.duo.uio.no/handle/10852/101084

Thomas, Sarina; Gilbert, Andrew; Ben-Yosef, Guy (2022). Light-weight spatio-temporal graphs for segmentation and ejection fraction prediction in cardiac ultrasound. MICCAI 2022. https://doi.org/10.48550/arXiv.2207.02549L. Available at https://arxiv.org/abs/2207.02549.

Tiago, C., Gilbert, A., Salem Beela, A., Aase, S.A., Snare, S.R., Sprem, J., and McLeod, K. “A data augmentation pipeline to generate synthetic labelled datasets of 3D echocardiography images using a GAN”. In IEEE Access. Vol. 10, 2022. pp. 98803-98815. DOI: 10.1109/ACCESS.2022.3207177.

4. Details of the impact

The research referenced in section 3 contribute to tackling the following major challenges:

- Making automatic measurements of clinically relevant parameters available in close-to-real time (Jahren, Gilbert, Andreassen, Thomas).
- Enabling training deep neural networks with limited cardiac ultrasound data and limited labels by deriving new methods for generating synthetic labelled data or providing anatomically valid augmentations (Gilbert, Tiago).

Spectral Doppler recordings are frequently used for examining heart wall motion, flow parameters, and valve diseases. In the Doppler spectrograms, clinical parameters are typically measured separately in multiple cardiac cycles. Carciac cycles are available from ECG recordings,

but ECG is not always acquired. Jahren et al. present a method for automatic detection of end-diastoles in Doppler spectrograms without ECG.

The prevalence of valvular diseases is increasing with age, and more than 10% of the population above 75 years of age are affected. Mitral regurgitation is the most common valvular disease, and echocardiography is the most frequently used imaging modality to evaluate mitral valve diseases. Localization of the mitral annulus and leaflets is the first step in order to calculate clinical measures for diagnosing pathologies and planning interventions of the mitral annulus. Andreassen et al. present methods for mitral annulus segmentation using deep learning in 3D echocardiography.

Reduced left ventricle outflow is an important marker of heart failure, and it can be quantified from the ejection fraction. The ejection fraction describes the volumetric blood fraction pumped by the heart in each heart cycle. Methods for segmenting the left ventricle can be used to derive ventricular volume, ejection fraction, and other relevant measurements. Robust automation of left ventricle segmentation and ejection fraction estimation are high priority tasks for modern echocardiographic systems. Thomas et al. present a robust, fast, and accurate method for left ventricle segmentation and ejection fraction estimation based on graph convolutional networks.

The amount of cardiac ultrasound datasets with associated labels suitable for robustly training a deep learning model is limited, both due to privacy issues in acquiring data, and the laborious and error-prone human labelling of 2D and 3D image ultrasound recordings. Gilbert et al. and Tiago et al. have developed approaches for synthesizing 3D echocardiography images paired with corresponding anatomical labels suitable for input for training deep networks.

5. Sources to corroborate the impact

Website for SFI Visual Intelligence: https://www.visual-intelligence.no/

Website for SFI CIUS: https://www.ntnu.edu/cius

Website for INIUS project: https://www.mn.uio.no/ifi/forskning/prosjekter/inius/index.html

Website for INCUS project: https://www.mn.uio.no/ifi/forskning/prosjekter/intelligent-cardiovascular-ultrasound-scanner/index.html

University of Oslo, Department of Informatics [Impact case #1]

Institution: University of Oslo
Administrative unit: Department of Informatics (IFI)
Title of case study: eHealth infrastructures
Period when the underpinning research was undertaken: 1994 - 2023
Period when staff involved in the underpinning research were employed by the submitting institution: 1994 - today
Period when the impact occurred: 1994 - today

1. Summary of the impact

The research promotes the introduction, uptake and scaling of digital infrastructures for the health sector (e-health infrastructures). In contrast to traditional project management emphasising control and, unfortunately not appropriately dealing with the complexity of today's digital world (which is reflected in frequent IT "scandals"), our work embodies alternative approaches. Our work has led to the formulation of alternative development strategies emphasising learning, more flexible architectures and adaptive governance mechanisms that have proven impactful. Our alternative approaches have ensured the scaling of the Health Information Systems Programme (HISP) across > 120 countries (giving it a footprint of 3.2 bn people's health data). Beyond the modern, platform-based, open-source software (DHIS2), our approach involves an extensive capacity-building network for health workers, managers and IT developers worldwide.

2. Underpinning research

Since the mid-1990s, a group of researchers at IFI (now formally allocated to the IS and DIN research groups) has pursued mutually reinforcing agendas of theoretical and practical work. Theory development has been pursued based on a) empirical studies of healthcare IT projects in the Norwegian context and b) action-oriented, policy-relevant establishment of health information systems in developing countries. Over decades, the core of this group includes Professors Margunn Aanestad, Ole Hanseth, Sundeep Sahay, Jørn Braa, and Eric Monteiro. With a core competence in informatics, the group has leveraged an international network of multidisciplinary competencies ranging from public health, health informatics, social sciences, to development studies. Concretely, central aspects of the basis for the impact have been;

- The pioneering theoretical work of articulating the novel Information Infrastructure perspective (Ole Hanseth and Eric Monteiro)
- The practical work with the post-apartheid South African health authorities to establish an information system that supported local decision making through the "information for action" vision (Jørn Braa, Calle Hedberg, Arthur Heywood).
- The insights from research on global software outsourcing (Sundeep Sahay) applied to the building of South-South-North networks in the HISP community
- The work on generification, scaling, and modernisation of the DHIS2 software (to allow it to be spread across diverse countries, to sustain the growth in uptake, and to migrate to modern technologies) has happened through an action-research approach. These activities were extraordinarily productive for novel research insights and provided opportunities for capacity building to hundreds of PhD and Master students, both from the global South and in IFI.
- A close collaboration with several health IT actors in the Norwegian health sector, such as a long-term (>25 years) collaboration with Oslo University Hospital, the South-East Regional Health Authority, AHUS hospital, Sunnaas Hospital, Østfold hospital, the Directorate of e-health, and through the SFI Center for Connected Care (2015-2023) also

Oslo Municipality and the eHealth industry. This has constituted joint research, student projects, advisory work, and public engagement in debates on e-health strategies in Norway. The research has constituted theory development (from an extensive empirical base) on core IS topics such as architecture, governance, standardisation, infrastructures and platforms.

The ongoing research on information infrastructures has happened in a dialogue between studies from the Norwegian healthcare setting (conducted mainly by Ole Hanseth, Margunn Aanestad, Miria Grisot, Bendik Bygstad, Egil Øvrelid, Alexander Kempton, Troels Mønsted and others.) and from the HISP countries (conducted by Jørn Braa, Sundeep Sahay, Petter Nielsen, Johan Ivar Sæbø, Terje Sanner, Kristin Braa, Eric Monteiro, and many others). This ongoing engagement between action research activities, case studies and joint theoretical analysis has been immensely productive for the generation of novel insights on many areas of e-health infrastructures:

- Alternative strategies on development, implementation, and scaling strategies have been developed (for instance, cultivation, bootstrapping, grafting, open generification and modular implementation strategies).
- Insights about the role of architecture have been developed - such as the advantages of flexible platform architectures over monolithic architectures and the need for integration of "light-weight" and "heavy-weight" IT architectures - two areas which have found great resonance among IT practitioners.
- This work has also driven research on governance approaches, such as standardisation strategies ('flexible standardisation', 'reflexive standardisation'), integration strategies, governing 'two-speed innovation' processes, the role of architecture-governance configurations, and realising 'digital public goods'.

This has again been the basis for continued engagement with the practice field in Norway and abroad on novel developments such as remote patient care/digital homecare, mobile data entry, disease surveillance, digital public goods, and health data analytics. The global ehealth infrastructure is also a crucial precondition for the frontier work with climate-health data. Thus, this group has delivered pioneering theoretical work on information infrastructure in combination with (and as a result of) research helping underserved communities, based on a pragmatic focus on achieving real-world benefits from digital infrastructures for healthcare.

3. References to the research

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Nicholson, B., Nielsen, P., Sahay, S., & Sæbø, J. I. (2022). *Digital public goods platforms for development: The challenge of scaling.* The Information Society, 38(5), 364-376. https://doi.org/10.1080/01972243.2022.2105999

Roland, L. K., Sanner, T. A., Sæbø, J. I., & Monteiro, E. (2017). *P for Platform. Architectures of large-scale participatory design*. Scandinavian Journal of Information Systems, 29(2), 1. https://aisel.aisnet.org/sjis/vol29/iss2/1/

Henfridsson, O. & Bygstad, B. (2013). *The generative mechanisms of digital infrastructure evolution*. MIS Quarterly. 907-931. https://www.jstor.org/stable/43826006 (Awarded MISQ Impact Award for highest 10-year impact)

Hanseth, O. & Lyytinen, K. (2010). *Design theory for dynamic complexity in information infrastructures: the case of building internet.* Journal of Information Technology. 25: 1-19. https://doi.org/10.1057/jit.2009.19

Braa, J., Hanseth, O., Heywood, A., Mohammed, W., & Shaw, V. (2007). *Developing health information systems in developing countries: The flexible standards strategy*. MIS Quarterly, 381-402. https://www.jstor.org/stable/25148796

Hanseth, O., Jacucci, E., Grisot, M., & Aanestad, M. (2006). *Reflexive standardization: Side effects and complexity in standard making*. MIS Quarterly, 563-581. https://www.jstor.org/stable/25148773

4. Details of the impact

The group - across various projects and activities in Norway and the Global South - has developed a unique international research profile but also significant practical impact. The group has engaged with practitioners in the Norwegian healthcare sector through collaborative project work, discussions, presentations of research in progress, and workshops. In particular, long-term collaborations have occurred with the IT department at Rikshospitalet (later Oslo University Hospital) since the mid-1990s, Sunnaas Rehabilitation Hospitals (since 2005) and for > 10 years also the regional Health Authority (Helse Sør-Øst RHF) which maintain Norway's largest digital infrastructure for its >80 000 employees. The regional collaboration has been significant for the region's IT strategy, reflected in the FIGI project and subsequent joint SFI application (2019), as well as collaboration on ongoing initiatives (digital homecare, AI implementation, data infrastructures). As one concrete example, the FIGI project's fundamental framework for distinguishing between 'lightweight' and 'heavyweight' IT has been taken up by many actors in the sector. This includes the Regional Health Authority, which used the framework both in its innovation strategy and its Enterprise Architecture. In general, they have worked to shift their IT strategy towards more agile and learning-oriented processes based on architecture choices that build on research-based knowledge. In addition, the framework was used in the national digital collaboration architecture developed by the Directorate of e-health. We have collaborated with Sunnaas Hospital on their development of digital services to support collaboration with the primary sector and patients at home. The research collaboration has been instrumental in giving the work legitimacy and has helped Sunaas establish a frontrunner position and spread the new service models of digital healthcare widely. Also the collaboration has been extensive around digital innovation initiatives with Østfold hospital (process innovation), Oslo Municipality (digital homecare) and AHUS hospital (digital homecare, AI implementation).

The group's research on handling complex sociotechnical infrastructures, encouraging bottom-up, user-driven, and learning-oriented approaches to the design of digital infrastructures, was also the base for group members' engagement in the broader public debates around the "One Citizen-One Record" national strategy and its implementation, (the Akson project, later Felles Kommunal Journal). A constellation of healthcare practitioners, researchers, and the IT industry was instrumental in re-directing a problematic project onto a more feasible trajectory during 2021-2023.

The open-source, web-based software platform DHIS2 (District Health Information System v2) supports data collection, management, and analysis. The development started as a doctoral research project in post-apartheid South Africa in 1994 and was based on a strong commitment to participatory design and action research. Healthcare workers were included in designing systems to support their work and provide "information for action". Today, DHIS2 is the world's largest Health Information Management System (HMIS) platform used by Ministries of Health in 80

countries in the global South and by NGOs in others, totalling 123 countries. It is estimated that 3.2 billion people (40% of the world's population) live in countries where DHIS2 is used. The system and the associated capacity building have revolutionised the collection and use of health data in developing countries. For instance, it offers health managers access to powerful analysis tools and health workers the ability to access and capture data on mobile devices. While DHIS2 was originally tailored for the health sector, due to its generic platform architecture, it is also used in other areas, such as water, sanitation and hygiene, health logistics, education, agriculture and climate health. HISP works in partnership with national and international actors, including Norad, the Global Fund, the Gates Foundation, PEPFAR, the CDC, Gavi, Unicef, and the WHO — with a combined investment of more than USD 21 million for 2022, supporting DHIS2 software development, implementation and capacity building. Through engaged scholarship and based on interventionist and action research approaches, we have followed and built our network of partners around design principles including 1) start small and keep simple, 2) user-led design integrating research, education and implementation, 3) build local capacity for scaling and sustainability, 4) link the local solutions to the global network, and 5) promote alliances through collective action.

HISP's achievements in strengthening health information systems in low- and middle-income countries are significant on their own. In addition, HISP has allied with universities in the global south and helped build alliances between public health and informatics/computer science departments. With support from HISP, cross-disciplinary and impact-oriented teaching programs at Master's and PhD levels are established in South Africa, Mozambique, Malawi, Tanzania, Ethiopia, and Sri Lanka, and more than 60 PhD candidates at UiO and over 500 Master's students globally have graduated within the program. Over 25,000 health workers have received training in health information management through the on-site and/or online DHIS2 Academies. As a result of the UN Secretary-General's High-Level Panel on Digital Cooperation, the Digital Public Goods Alliance was established in 2018. The government of Norway plays a leading role in this effort to accelerate the attainment of sustainable development goals by facilitating the discovery, development, use of, and investment in digital public goods (DPG). DHIS2 has been a decisive motivation factor for this endeavour and has been promoted as an exemplar DPG.

Since 2017, and renewed in 2022, the HISP Centre has been a World Health Organization (WHO) Collaborating Centre for Innovation and Implementation Research for strengthening health information systems. In this capacity, HISP partners with WHO and its Member States to strengthen Health Information Systems implementations and data use at the country level. This partnership will expand and improve the DHIS2 Health Toolkit, including developing metadata packages for new health programs, implementation tools, and technical guidance for integrated routine health information systems. To date, 64 primarily low- and middle-income countries have installed standards-based metadata packages from the WHO DHIS2 toolkit with support from partners, moving towards integrated national health data platforms that serve data analysis and data use at all levels of public health services based on WHO recommended data standards. This work was also foundational in helping 60 countries rapidly adapt existing DHIS2 systems to support national disease surveillance and vaccination problems during the COVID-19 pandemic.

The DHIS2 Annual Conference is the biggest HISP/DHIS2 yearly event and provides an opportunity for the global DHIS2 community to meet at UiO — a diverse group including implementers, developers, ministry representatives, technical partners, donors, and other DHIS2 experts from around the world — to meet and share experiences with DHIS2, learn about the latest developments and innovations, and make connections that can lead to new partnerships and collaborations. In 2023, the conference attracted 414 in-person participants, representing 72 different countries and 169 organisations, and additional more than 800 online participants. The programme includes the introduction of new and upcoming features from the DHIS2 core

development team, presentations by national Ministries of Health and global public health partners such as WHO and the CDC, community-driven presentations selected from an open call for presentation topics and ample opportunities to network with peers and experienced DHIS2 implementers.

5. Sources to corroborate the impact

1. Speaking at a UN event on The Future of Digital Cooperation in 2022, Norway's Prime Minister Jonas Gahr Støre praised DHIS2 as a free and open tool that revolutionises how countries can collect and use health data: https://dhis2.org/unga-dpg-dpi-event/
2. Norway's Prime Minister Presents DHIS2 as Leading Example of a Digital Public Good: https://dhis2.org/new-america-digital-public-goods/
3. DHIS2 presented at SDG Digital 2023, an event hosted by the International Telecommunication Union (ITU) and United Nations Development Programme (UNDP) as part of the UN's SDG Action Weekend, to highlight how digital solutions can help get the world back on track toward the Sustainable Development Goals (SDGs), which are now at the halfway point toward 2030. As part of the event, one impactful digital solution was chosen for each of the 16 SDGs, with DHIS2 selected to represent SDG3: health.
4. DHIS2 mentioned in the Norwegian Aid Strategy from 2022: "Better Health, Better Lives. Combating Non-Communicable Diseases in the Context of Norwegian Development Policy (2020-2024)"
5. The United States Centers for Disease Control and Prevention (CDC) EID Journal elaborates on how DHIS2 has been used to emplace more effective surveillance systems for COVID-19 using lessons from the Ebola outbreak: https://wwwnc.cdc.gov/eid/article/28/13/22-0711_article
6. The German Federal Ministry of Economic Cooperation and Development describes the role of DHIS2 in strengthening the health information systems in Bangladesh: https://health.bmz.de/wp-content/uploads/studies/HIS_Bangladesh_long_EN.pdf
7. HISP was awarded the University of Oslo's Innovation Prize in 2013, 2020 the Roux Prize, an international award for turning evidence into health impact, and the Association of Information Systems (AIS) Impact Award in 2023 - an award that "recognizes information systems research with widespread impact on practice in business and society".
8. The practitioner-oriented book entitled "Information Infrastructures within European Health Care: Working with the Installed Base" on Springer (2017), pulling together health infrastructure studies from our European researcher network has >150,000 downloads.
9. The research conducted in the SFI Center for Connected Care resulted in the practitioner-oriented publication "Handbook in Health Innovation - Research-based tools and methods for shaping the health service of the future" in Norwegian and English.
10. When the COVID-19 pandemic hit Norway in March 2020, it quickly became apparent that there were no digital health tools available to help local authorities organise their disease surveillance. The Norwegian Association of Local and Regional Authorities (KS) chose to use DHIS2, and just three months after the first COVID-19 cases were registered in Norway, KS's DHIS2 system was ready for municipalities to take into use. By the end of 2021, more than 3,000 users in 130 municipalities were using DHIS2, registering more than 330,000 people and over 1,500,000 events.

University of Oslo, Department of Informatics [Impact case #2]

Institution: University of Oslo
Administrative unit: Department of Informatics (IFI)
Title of case study: Knowledge-Driven Transformation of Engineering and Operations in Capital-Intensive Energy Facilities
Period when the underpinning research was undertaken: 2016-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2016-ongoing
Period when the impact occurred: 2019-ongoing

1. Summary of the impact

The KONKRAFT assessment of competitiveness of the Norwegian Energy Sector [1] identified manual and document-based processes as being driver of costs and a barrier to digital transformation and future competitiveness. These inefficient processes increase cost, in some areas by 20%, and reduce the performance of the built facility. Knowledge representation, or *Semantic asset modelling*, provides a theoretical and practical basis for moving from existing, document-based processes to data-oriented processes. The SIRIUS Centre for Research-Driven Innovation has provided methods and tools that have enabled a productive series of joint industry and collaborative projects in the oil & gas sector demonstrating how engineering and operational business processes in EPC companies (Aker Solutions, Aibel, TechnipFMC), operating companies (Equinor, AkerBP), and equipment vendors (Siemens, Bosch, Grundfos) can be transformed. The results have gained international attention. They have been anchored through open-source software, a DNV Recommended Practice, a new standard in the DEXPI organization for process design, contributions to IOGP practices, and a new ISO standard on Ontology Based Interoperability.

2. Underpinning research

Fundamental ICT research	Translational research	Application and demonstration
• Reasonable ontology templates (OTTR). • IDO – a foundational ontology for engineering data. • High-performance graph databases and query tools.	• Reference architecture and best practice for digital twins. • Information Modelling Framework (IMF) • Semantic representation of requirements. • Semantic management of identifiers in engineering data.	• READI joint industry project: Reference Designation System for Oil & Gas and IMF concept. • Digital Design Basis JIP. • DISC JIP: DEXPI standardization, integration of IMF with Industrie 4.0 standards, and implementation of IMF in industry.

The research focuses on the design of engineering-specific knowledge representation languages and associated methods. The languages and methods exploit, in a coherent framework, opportunities that

come from semantic web technologies to create interoperable knowledge graphs that can be queried, and logic-based languages that provide a precise declarative semantics. Together, they enable the use of automated reasoning to check the integrity and correctness of information.

The research has built on the translational ideas developed in the Optique EU project, where ontology-based data access was demonstrated in use for subsurface and operations data. Our work here can be classified into three categories. We build on a foundation of fundamental results with a set of translational methods. These then support application and demonstration within the engineering domain.

Reasonable Ontology Templates (OTTR) (https://www.ottr.xyz) is a language developed by SIRIUS researchers that simplifies the development and maintenance of knowledge models by engineers who are not experts in semantic technology [2], [3].

The **Industrial Data Ontology** is a vocabulary of relevant entities of the domain of interest with relationships that helps users build consistent models, build hierarchies of reference data, avoid categorical mistakes, and maintain data quality through the assistance of a tool that uses formal logic to check model integrity. IDO is under standardisation as a New Work Item in ISO Technical Committee 184 Sub-Committee 4 Industrial Data.

Implementation of these methods depends on access to **high-performance graph databases and query tools**, as developed in the Optique project [4]. We have worked further with the University of Oxford and Free University of Bolzano and their start-up companies, Oxford Semantic Technologies and Ontopic, to advance their methods and the RDFox and ONTOP software tools.

Translation to industrial application is done using **digital twins** as an implementation pattern. We have developed a simple but effective conceptual model of twins that aims to develop a best practice for digital twins for oil & gas [5], [6].

The **Information Modelling Framework** language **(IMF)** [7], [8] is a language that allows the construction of well-structured information models of engineered systems. It provides a way of moving from document-based engineering to data-based engineering in a way that is relevant to engineering practitioners. IMF makes use of the OTTR and IDO languages. The key feature of IMF is the capability to express and separate four different chains through a body of technical information: requirement/solution, abstraction, topology connectivity, and type/class hierarchies. IMF also supports different modalities that can be used to capture the different contexts that arise through the project lifecycle. IMF provides a bridge between knowledge representation technologies and systems engineering approaches.

This work was supplemented by work that provided simple semantic **representation of requirements** [9] and the selection and mapping of **identifiers** in engineering information systems [10].

The **application and demonstration** work took these methods and generated industrial results in collaboration with partner companies. The RDS for Oil & Gas [11], Digital Design Basis JIP [12] and DISC project with DEXPI participation [13] are described in the impact section below.

The SIRIUS team involved Dr. Martin Skjæveland (UiO), Dr. Baifan Zhou (UiO), Prof. Arild Waaler (UiO), Dr. David Cameron (UiO), Dr Dag Hovland (UiO, then Bouvet), Dr. Johan W. Kluwer (DNV), Dr. Foivos Psaromattis (UiO), Prof. Dimitris Kiritsis (UiO), Dr Evgeny Kharmalov (Bosch and UiO), Prof. Ian Horrocks (Oxford), Prof. Boris Motik (Oxford) and participants from SIRIUS partners Equinor, Bosch, DNV, Computas, Bouvet, and Aibel. We have collaborated with Aker BP, Aker Solutions, TechnipFMC, ConocoPhillips, Petrobras, Siemens AG, Siemens Energy, Grundfos, Standards Norway, NTNU,

University of Western Australia, Federal University of Rio Grande do Sul and Federal University of Espirito Santo.

3. References to the research

We have combined the research and impact references into a single list.

[1] KonKraft, 'Project Competitiveness – changing tide on the Norwegian continental shelf - Summary and recommendations from the Committee', KonKraft, Oslo, Jan. 2018. Accessed: Dec. 12, 2021. [Online]. Available: https://konkraft.no/wp-content/uploads/2020/03/Summary_and_recommendations.pdf

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[13] D. B. Cameron, W. Otten, H. Temmen, M. Hole, and G. Tolksdorf, 'DEXPI process: Standardizing interoperable information for process design and analysis', Comput. Chem. Eng., vol. 182, p. 108564, Mar. 2024, doi: 10.1016/j.compchemeng.2023.108564.

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4. Details of the impact

As noted above, the research and innovation work reported here built on the impact and industrial network established by the **Optique EU project** (2014-2016) [4]. The core network in Optique became central to the SIRIUS Centre for Research-Driven Innovation in 2015. Early in the life of the centre, it became clear that effort would be needed to ensure that fundamental IT research answered real business challenges of partner companies. SIRIUS thus established a **beacon program** on digital twins and digital field development [14]. This created a portfolio of projects with the explicit purpose of deriving impact from SIRIUS' research agenda for knowledge representation and graph databases.

The agenda for this work was set by workshops with SIRIUS partners (Equinor, DNV, SLB, IBM, SAP, OSISoft) and other companies (Siemens, Total, Shell, Aibel, Aker Solutions, TechnipFMC). We pursued a dissemination strategy that involved business-oriented presentations at events organized by NORWEP, EU PPPs (BDVA and SPIRE) and workshops in Rio de Janeiro and Houston. This resulted in PeTWIN, a collaboration with Petrobras, Shell, Equinor and UFRGS, financed by the RCN and FINEP.

Collaboration with DNV and Equinor resulted in engagement with the **NORSOK Z-TI** project and its successor, the **READI Joint Industry project**. **The economic driver here was the potential to reduce procurement costs in field development by up to 20%.** Here the SIRIUS research team was a key provider of tools and ideas behind the implementation of the project. READI resulted in three deliverables: the ISO/IEC81346 RDS for oil & gas [11], IMF concept paper, and a semantic representation of requirements [9]. The work on requirements is being developed as a course program, staff exchanges and workshops with dissemination in Brazil and the US, through the DSYNE INPART network (https://dsyne.no).

The READI JIP identified the need for **IMF** as a tool to link the RDS for oil & gas to engineering data and requirements. IMF provides a rich information model that supports structuring of engineering data in an effective way that also supports reasoning about requirements [8]. At the same time, 2018, participants in READI, Aibel, Aker Solutions and TechnipFMC, became partners in SIRIUS.

This provided an opportunity for a further **Digital Design Basis JIP**, organized within SIRIUS, that attempted to model design bases from three operating companies (Equinor, Lundin and AkerBP) as semantic data, so that it could be used by three vendors (Aker Solutions, TechnipFMC and Aibel) [12]. This prototyping work informed software development by Aize AS, TechnipFMC, Equinor and Aibel. **Aker Solutions' business case for the project identified cost savings of at least NOK 1.6 billion a year across the Norwegian Continental Shelf just in early phase design.**

This work was followed up further by the **DISC initiative in the Yggdrasil field development**. This initiative is a collaboration between Equinor, AkerBP, Aker Solutions and Aibel, where operators and vendors agree to pilot new ways of transferring engineering data during a field development project, with the aim of moving away from document-based work processes. This initiative has validated the IMF, the RDS for oil & gas and IDO. In addition, the project has been a leading implementer of **Industry 4.0 standards** such as AutomationML, NAMUR, Asset Administration Shell and DEXPI. This has resulted in SIRIUS establishing new collaborations with German academia and industry, notably through the publication of an IMF-inspired DEXPI standard for process design data [13]. We have also developed a library or IMF types for design of facilities.

OTTR has also been adopted as a **tool by third parties**. The group of Prof. Melinda Hodkiewicz at the University of Western Australia uses the tool to manage ontologies of maintenance systems for mining companies (BHP and RioTinto) [3] and is active in the IDO work. Aibel, DNV, and Grundfos use

OTTR in their development. A recent start-up, Data Treehouse AS (https://www.data-treehouse.com), uses OTTR as a core technology in their products.

SIRIUS is among the founding members of the recently created Knowledge Graph Alliance (https://www.kg-alliance.org/) as one of the results of the OntoCommons EU project (https://ontocommons.eu/). **IMF** principles have been used in the development of the OntoCommons EcoSystem (OCES) and partially demonstrated in OntoCommons demonstrators. SIRIUS developed collaborations with Industrial Ontology Foundry (https://oagi.org/pages/industrial-ontologies) and organised, together with DNV, the first open workshop of IOF in Oslo in 2019 with about 120 participants.

SIRIUS methods are being applied and further developed in four ongoing Horizon Europe projects in the manufacturing sector with UiO as partner: Re4Dy (https://re4dy.eu), Plooto (https://www.plooto-project.eu), Tec4MaaSEs (https://tec4maases.eu), and Sm4rtenance (https://sm4rtenance.eu).

Initiatives ongoing to realize the full potential of this transformation include: (1) publication of IMF as a DNV Recommended Practice; (2) communication through the IOGP digital initiative https://www.iogp.org/workstreams/engineering/standards/digitalization/ and CFIHOS https://www.jip36-cfihos.org; (3) collaboration with a revitalized POSC Caesar Association, who is developing IDO and also collaborating in the fPVN – Arrowhead EU project https://fpvn.arrowhead.eu/fpvn-arrowhead/; (4) participation in the new ISO standard ISO/NP 23726 Ontology Based Interoperability. IDO will be part 3 of this standard; (5) use of the DSYNE network to catalyze further work and support adoption in Brazil and the US; support of new and existing software vendors in the development of industrial-strength tooling; (6) contributions to standardization work in the Industrial Digital Twin Association, NAMUR and DEXPI and (7) collaboration with stakeholders in the electrical energy sector including Statnett and Statkraft, and construction sector to prove our methods as a unifying tool for discipline-specific data models, such as CIM and BIM.

Note that we have adopted a dual publication strategy. The fundamental research is published in the semantic technologies literature [2], [3], [10], whereas the translational and application work has been published in the relevant manufacturing [8] or chemical engineering [12], [13] literature. We also present at trade conferences, such as the annual NFEA Digitalization conferences.

5. Sources to corroborate the impact

See references 7-14 in section 3.

- OTTR website with open-source software: https://ottr.xyz/
- IMF website: https://www.imfid.org
- DEXPI Process https://dexpi.org/dexpi-process-specification-1-0-released/.
- POSC Caesar association https://www.posccaesar.org/projects_and_workgroups/
- READI JIP https://readi-jip.org

Personal references in collaborating companies:

- Jann Kåre Slettebakk, Vice President, Aker Solutions.
- Torleif Saltvedt, Senior Advisor Information Management, Equinor.
- Ellen C. Karlsen, Digitalisation and Improvement Manager, Aibel.
- Kirsten Helle, Manager Technical Safety & Reliability, TechnipFMC.
- Mikkel H. Brynildsen, Chief Data Scientist, Grundfos.
- Kjell Eriksson, Vice President, DNV.

University of Oslo, Department of Informatics [Impact case #4]

Institution: University of Oslo
Administrative unit: Department of Informatics (IFI)
Title of case study: Low-cost miniaturized UWB antenna
Period when the underpinning research was undertaken: 2011 - 2021
Period when staff involved in the underpinning research were employed by the submitting institution: 2011 - 2024
Period when the impact occurred: 2020 - 2024

1. Summary of the impact

The WellSafe project funded through RCN NANO 2021 and related research efforts brought forward new and miniaturized Ultra-Wideband (UWB) antenna designs enabling UWB sensing in high-volume / low-cost consumer products. At the time of completion, the resulting design and corresponding radar module were the smallest reported globally and disrupted UWB antenna and module design for UWB sensor applications. The key challenges addressed were how to achieve directivity, minimize loss and at the same time make the antenna immune to its surroundings. The design was commercialized by the project owner Novelda AS and is currently deployed in high-volume consumer applications and further formed the basis for several UWB radar module products. These designs now serve as reference for UWB sensor module design across the global industry.

2. Underpinning research

During the RCN StorIKT project MELODY (2008-2011), the NANO group started exploring more system-level aspects beyond integrated circuit design especially focused on Ultra-Wideband radio transceivers. This included research on antennas and modules and as a result the group also established a new radio-lab with anechoic chamber when moving to IFI-2 in 2011 (Picolab). In the coming years, the group built expertise on RF/antenna design and characterization. This activity was headed by Professor Tor Sverre Lande and several PhD-students were involved.
In the first phase, the research focused on biomedical applications of UWB sensing technology where near-field effects on antenna performance had significant impact and were studied in detail (References [1]-[3] below).

Later, the research expanded to also include through-air sensing for a wide range of applications. The common denominator was the high bandwidth (3.1 – 10.6 GHz) posing several design challenges compared to conventional narrow-band design. Several design-techniques were explored including 3D-printing of antennas and use of new materials (References [3]-[6] below). The research also involved collaboration with industry like the RCN-funded BIA projects UWBPOS and Ventricorder coordinated by Novelda AS. Kristian Kjelgård who is now an Associate Professor at the group was employed as a PhD-student and Post.Doc in these projects and later PhD-student Mathias Tømmer was also involved. In 2017, the group became partner in the RCN NANO-2021 project “WellSafe” (2017-2021) owned by Novelda AS with Professor Dag T. Wisland and Professor Tor Sverre Lande coordinating the research. This project defined a new direction of the research where the goal was to realize miniaturized and low-cost UWB-antennas for high-volume consumer applications. Such antennas possible to manufacture with low-cost materials and capable of mass-production had not been reported and Novelda AS had also tried to source R&D services from leading international R&D institutions and consultants without success. Researchers Kjelgård and

Tømmer were the key researchers from UiO in the project and through a close collaboration with Novelda and large international semiconductor and consumer electronics companies, several novel antenna design concepts and prototypes were developed and tested. A key challenge was to also guarantee regulatory compliance across production variation and across multiple end-product variants. The resulting prototypes demonstrated the feasibility of miniaturized UWB antennas in low-cost materials and were commercialized and deployed in high-volume products as described in the section below. Due to the commercial nature of the project and need for IP protection by the project owner, the results were not published through the project, but scientific publications building upon the project results are expected going forward. In addition, the research has also led to contributions to the upcoming IEEE 802.15.4ab standard currently being developed.

Key researchers:

Research execution: Associate Professor Kristian G. Kjelgård (entire period, PhD→Post.Doc→Researcher→Associate professor), PhD student Mathias Tømmer (2015 to end of project period)

Research coordination and management: Professor Dag T. Wisland (entire period) and Professor Tor Sverre Lande (entire period).

3. References to the research

[1] K. G. Kjelgård, M. Høvin and T. S. Lande, "Body-coupled, wideband antennas," *2015 IEEE Biomedical Circuits and Systems Conference (BioCAS)*, Atlanta, GA, USA, 2015, pp. 1-4, doi: 10.1109/BioCAS.2015.7348386.

[2] M. Tommer, K. G. Kjelgård and T. S. Lande, "Body coupled wideband monopole antenna," *2016 Loughborough Antennas & Propagation Conference (LAPC)*, Loughborough, UK, 2016, pp. 1-5, doi: 10.1109/LAPC.2016.7807483.

[3] T. Lauteslager, M. Tommer, K. G. Kjelgård, T. S. Lande and T. G. Constandinou, "Intracranial heart rate detection using UWB radar," *2016 IEEE Biomedical Circuits and Systems Conference (BioCAS)*, Shanghai, China, 2016, pp. 119-122, doi: 10.1109/BioCAS.2016.7833739.

[4] K. V. Hoel, S. Kristoffersen, J. Moen, K. G. Kjelgård and T. S. Lande, "Broadband antenna design using different 3D printing technologies and metallization processes," *2016 10th European Conference on Antennas and Propagation (EuCAP)*, Davos, Switzerland, 2016, pp. 1-5, doi: 10.1109/EuCAP.2016.7481620.

[5] V. Midtbøen, K. G. Kjelgård and T. S. Lande, "3D printed horn antenna with PCB microstrip feed for UWB radar applications," *2017 IEEE MTT-S International Microwave Workshop Series on Advanced Materials and Processes for RF and THz Applications (IMWS-AMP)*, Pavia, Italy, 2017, pp. 1-3, doi: 10.1109/IMWS-AMP.2017.8247374.

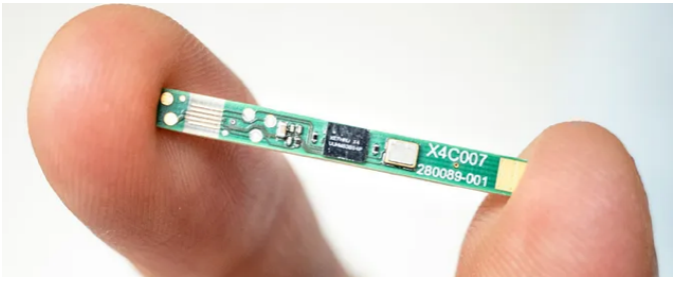
[6] K. G. Kjelgård and T. S. Lande, "Shielding of Tri-Patch Antenna Using 3D Printed Composite Carbon/PLA Absorber for Ultra Wideband Snow Radar Systems," *2021 IEEE International Geoscience and Remote Sensing Symposium IGARSS*, Brussels, Belgium, 2021, pp. 1039-1042, doi: 10.1109/IGARSS47720.2021.9554338.

4. Details of the impact

As described in section 2 above, a long-term research effort on UWB antenna / module design and characterization resulted in disruptive results in terms of miniaturization and low-cost implementation of UWB antennas. In terms of impact this mainly occurred through the

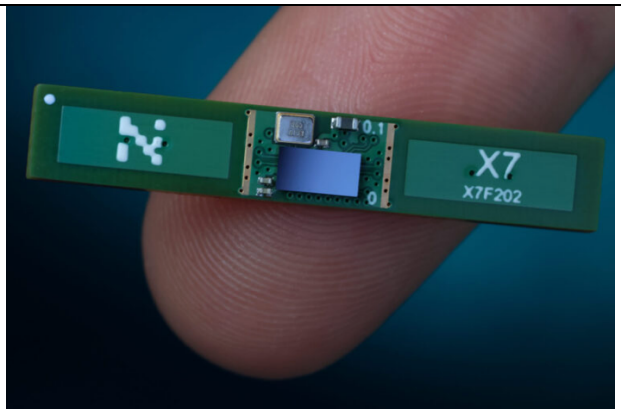
collaboration in the RCN WellSafe project which led to tangible results currently deployed in high-volume consumer products, but also transfer of competence from university research to the industry. In the final stage of the WellSafe project PhD student Mathias Tømmer moved to Novelda AS as a lead antenna designer enabling scaling the specific project results into multiple product families, leading to a strong competitive advantage towards international competitors enabled by scientific research. Associate professor Kristian G. Kjelgård is still with the NANO group at UiO and is securing continuation of the scientific research within the field at UiO.

The most tangible and visual result of the impact is the Novelda X4C007 module deployed in several different Lenovo laptop models [7]. The size of this module is 3x30mm and at that time the smallest self-contained UWB sensor module in the world. The purpose of this sensor was to enable fast and no-touch user log-in and immediate lock-on-leave to improve user experience, security and save energy. Estimated energy-savings were around 20%. Researchers mentioned above were directly involved in the design- and prototype phases including Lenovo and their ecosystem partners (names not disclosed due to NDA). The X4C007 product including the embedded UWB antennas is illustrated below:

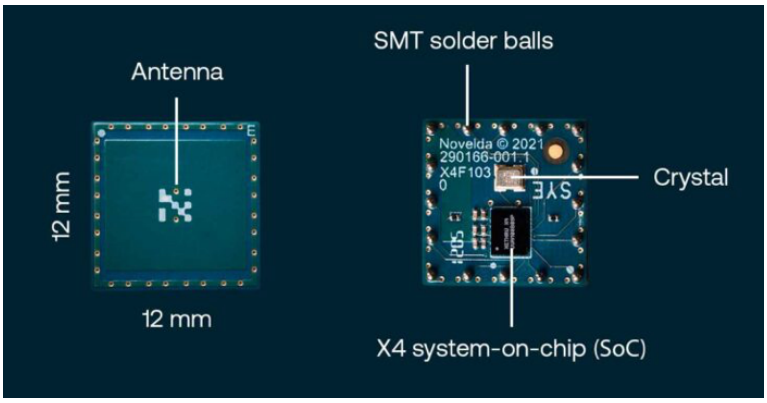


Following Apple releasing UWB for ranging purposes in their iPhones, the deployment of UWB sensor technology from Novelda AS was the first high-volume UWB sensor in consumer products which made a strong impact internationally and also contributed to large international companies like NXP, Qorvo, Qualcomm, Samsung, Huawei initiating development of UWB sensing products. This also led to a revision of the existing UWB communication standard IEEE 802.15.4z, where sensing has been included and will be released as the new IEEE 802.15.4ab standard [8]. Researchers from UiO together with Novelda have been heavily involved in standard development together with the global UWB ecosystem players.

Recently, UWB sensor product development has also reached the automotive industry due to its competitive advantage over 60 GHz radar technology when it comes to energy efficiency, cost, and robustness. The key application is Child Presence Detection (CPD) in cars driven by the very sad fact that several children die every year due to heatstroke because they are left behind in overheated cars. As a result, NCAP has made mandatory to have systems that detect children in the car and set an alarm if the driver leaves and lock the door with the child left in the car. Like competitors, Novelda just announced a CPD product where the antenna / module design origins from results brought forward in the mentioned research project [9]. The most recent UWB sensor module is illustrated below.



Different from the X4C007 module, the X7F202 module has two transmitter and two receiver channels to support beamforming making the design slightly larger. This research results from designing this chip / module has also been accepted for publication at the prestigious IEEE International Solid-State Circuit Conference (ISSCC-24) in February 2024 [10]. Another tangible documentation of the impact is the X4F103 [11] module targeting general-purpose products within building automation, appliances etc as illustrated below.



5. Sources to corroborate the impact

[7] https://medium.com/novelda-news/two-new-lenovo-laptops-with-the-novelda-hpd-sensor-launched-at-ces-2021-c82fc67f3ee7
[8] https://www.ieee802.org/15/pub/TG4ab.html
[9] https://novelda.com/news/novelda-announces-new-ultra-wideband-child-presence-detection-cpd-sensor-2
[10] http://submissions.mirasmart.com/ISSCC2024/PDF/ISSCC2024AdvanceProgram.pdf (page 17).
[11] https://www.hackster.io/news/novelda-s-tiny-uwb-x4f103-uses-impulse-radar-to-monitor-movement-right-down-to-individual-breaths-3614aa2b03d0

University of Oslo, Department of Informatics [Impact case #5]

Institution: University of Oslo
Administrative unit: Department of Informatics (IFI)
Title of case study: Transport Services (TAPS)
Period when the underpinning research was undertaken: 2010 – now
Period when staff involved in the underpinning research were employed by the submitting institution: 2009 – now
Period when the impact occurred: 2018 – now

1. Summary of the impact

TAPS replaces Berkeley sockets with an IETF standard API that avoids the compile-time binding of applications to protocols and network interfaces. This makes the Internet altogether much more flexible and easier to upgrade. It facilitates access to new services and offers Operating System and middleware designers an opportunity to differentiate their TCP/IP stack implementations.

Apple is one of the main contributors to the TAPS standard and has followed TAPS principles in their "Network.Framework" API, which is offered to all Apple developers since 2018.

Rumours talk of at least one more large implementation that is under development. The TAPS standard is now very close to finalisation; it is expected that the biggest impact will happen after publication.

2. Underpinning research

The academic literature contains many proposals for more flexible network APIs, dating several decades back, with no real-life impact whatsoever. The relevant difference for TAPS to have an impact, and thus the novelty of the research leading up to it, was to:

1. Identify how to carry out this work in a way that can realistically be standardised by the Internet Engineering Task Force (IETF) (e.g., this is why, different from all other prior proposals, TAPS follows a *bottom-up* design),
2. Design and implement a TAPS prototype to demonstrate how the underlying ideas work.

This involved:

- Carefully designing a suitable API: on the one hand, as much as possible must be abstracted, as exposing unnecessary elements makes the application-protocol binding more rigid. On the other, some services *must* be exposed, or an application can never make use of them. To achieve this, we:
    - Identified the services offered by a suitable set of transport protocols at the right abstraction level *([RFC8303], primarily our work, January 2016 – February 2018)*.
    - Systematically identified which services require "application-specific knowledge" (knowledge that only applications have), making them indispensable in the API surface, and identified mismatches and redundancies *([RFC8923], only our work, December 2015 – October 2020)*,
    - Carried out the final API design *([1] and [draft-ietf-taps-interface], where we are a major contributor, April 2018 – now)*.
- Exploring (measuring) the feasibility of using various network protocols mechanisms (e.g., the DiffServ Code Point (DSCP)) across the "best effort" Internet *([3][4], primarily our work)*.

- Designing, implementing and evaluating machinery that shows how to dynamically choose and configure protocols and network interfaces, even when a protocol may not be supported over an Internet path. *([2], joint work with partners in the NEAT project)*

Most of the underpinning research was carried out in the EC H2020 project "NEAT", and some more follow-up work was done in the national "toppforsk" project "OCARINA" that was funded by the Norwegian Research Council.

Relevant key researchers at the unit:

Michael Welzl, full professor
Stein Gjessing, full professor
Naeem Khademi, postdoctoral researcher from 2015 to 2018
Runa Barik, Ph.D. student from 2014 to 2019

3. References to the research

- *[1]* Michael Welzl, Safiqul Islam, Michael Gundersen, Andreas Fischer: "Transport Services: A Modern API for an Adaptive Internet Transport Layer", IEEE Communications Magazine 59(4), April 2021. DOI 10.1109/MCOM.001.2000870
- *[2]* Naeem Khademi, David Ros, Michael Welzl, Zdravko Bozakov, Anna Brunstrom, Gorry Fairhurst, Karl-Johan Grinnemo, David Hayes, Per Hurtig, Tom Jones, Simone Mangiante, Michael Tuexen and Felix Weinrank: "NEAT: A Platform- and Protocol-Independent Internet Transport API", IEEE Communications Magazine 55(6), 2017. DOI 10.1109/MCOM.2017.1601052
- *[3]* Runa Barik, Michael Welzl, Gorry Fairhurst, Ahmed Elmokashfi, Thomas Dreibholz, Stein Gjessing: "On the Usability of Transport Protocols other than TCP: A Home Gateway and Internet Path Traversal Study", Elsevier Computer Networks, Volume 173, 22 May 2020. DOI 10.1016/j.comnet.2020.107211
- *[4]* Runa Barik, Michael Welzl, Ahmed Elmokashfi, Thomas Dreibholz, Safiqul Islam, Stein Gjessing: "On the Utility of Unregulated IP DiffServ Code Point (DSCP) Usage by End Systems", Elsevier Performance Evaluation, vol. 135, August 26, 2019. DOI 10.1016/j.peva.2019.102036, ISSN 0166-5316.
- *[RFC8303]* Michael Welzl, Michael Tuexen, Naeem Khademi (eds.): "On the Usage of Transport Features Provided by IETF Transport Protocols", RFC 8303 (Informational), February 2018. DOI 10.17487/RFC8303
- *[RFC8923]* Michael Welzl, Stein Gjessing: "A Minimal Set of Transport Services for TAPS Systems", RFC 8923, (Informational), October 2020. DOI 10.17487/RFC8923
- *[draft-ietf-taps-interface]* B. Trammell, Ed., M. Welzl, Ed., R. Enghardt, G. Fairhurst, M. Kuehlewind, C. Perkins, P. Tiesel, T. Pauly: "An Abstract Application Layer Interface to Transport Services", IETF Internet-draft (work in progress) draft-ietf-taps-interface-24, December 2023, available from https://datatracker.ietf.org/doc/draft-ietf-taps-interface/24/

4. Details of the impact

The theoretical foundations of networking that were laid out in the OSI model expect much more flexibility than the Internet has ever achieved: they include the ability to seamlessly change protocols at each layer, because the internals of a layer are not visible to the users of this layer. Until now, Internet standards have never followed this design. Changing protocols at the transport layer is practically impossible: without TAPS, an application that is written against TCP cannot seamlessly use other protocols *and benefit from the mechanisms that these protocols offer*.

Using other, more modern protocols, along with mechanisms that test whether these protocols "work" across an Internet path and otherwise fall back to TCP, is a difficult effort for application programmers. It is therefore only worthwhile for giant industry players such as Google (who have done exactly this with QUIC, in their Chrome browser).
This complexity makes it hard for SMEs to write competitive network code.

TAPS moves all the functionality that is related to selecting, testing, configuring and utilising a transport protocol inside the transport layer, where it belongs. Applications specify their needs and get them satisfied, following the Internet's "best effort" model; this allows to upgrade the network below the API. Specifically, TAPS:

1. Makes it much easier for programmers to benefit from modern protocols and mechanisms (and their code will automatically benefit from new protocols and mechanisms even when these are deployed in later updates of the network stack).
   Beneficiaries: SMEs which need to write efficient network code.
2. Creates new opportunities for diversification of the network stack below the API. *Beneficiaries: Developers of middleware, network libraries, or Operating Systems.*
3. Creates new opportunities for diversification inside the network, as supporting a new, previously unused, protocol may suddenly become beneficial for customers. As we and others have shown, this even goes beyond "just" IETF transport protocols, and it can help the deployment of novel network architectures.
   Beneficiaries: Network service providers.

To date, only impacts 1) and 2) have happened, as Apple has made use of TAPS principles in their "Network.Framework" API, which is offered to all developers since the beta versions of iOS 12 and macOS Mojave, in 2018.

Note that, after more than a decade in the making, the TAPS standard is not yet finished. If a company offers a TAPS API before the final specification is published, there is a risk of having to change the API for programmers due to a standard update – for this reason, steps towards TAPS have been rather cautious, but this is expected to change upon publication. As Apple has gradually taken more and more of the TAPS functionality on board, the flexibility of their network stack has already been increasing – for example, since 2022, a network connection can use TCP or QUIC without the application being aware of the change.

How has the research underpinned the impact, how was the impact achieved:

We led the entire effort. This involved:

- **Research prototype #1:** technical proof that the TAPS idea 1) *can* efficiently be implemented, and 2) *can* yield technical benefits. Each of these arguments were developed with results from a master thesis that we guided, and a published paper from the thesis.
- **Creating the TAPS Working Group.** This was an intense community building effort: creating a mailing list and webpage, discussing the ideas there, writing several documents and convincing colleagues to write documents (to outline how TAPS could work and why it is needed), as well as organizing three events at IETF meetings (a "bar BoF" and two "BoFs"). This work, which received a large amount of help from Gorry Fairhurst at the University of Aberdeen in particular, is documented here:
  https://sites.google.com/site/transportprotocolservices/home
  It led to the **creation of the TAPS Working Group on 24. September 2014.**

- **Creating and technically leading the European H2020 research project "NEAT" to accompany the TAPS effort.** We formed the consortium, led the technical proposal writing effort, and were technical manager of this project, which ran from March 2015 until April 2018 (top scores at the final review). Details are here: http://neat-project.org
  The NEAT code is **research prototype #2**, which allowed us to maintain a leading role in the early design stages in the TAPS Working Group.
- **Continued involvement in TAPS until the time of writing.** Including group creation, this has been more than a decade of intense IETF work. At the time of writing, the group's github repository shows 813 closed issues and 638 closed PRs; the latest published interface draft is currently at version 25, and there are three drafts in total that the group is working on. We are editor of one draft, co-author of one draft, and a minor contributor to the third draft (which is the shortest, easiest document).

Many dissemination and communication efforts have taken place – including, but not limited to the activities of the NEAT project. If TAPS will be a major success (beyond "just" Apple), community uptake will happen automatically via the IETF after publication of the RFCs.
This remains to be seen.

We do not claim to have actively involved Apple: this contact was established by TAPS collaborator Brian Trammell (ETH Zürich at the time, now with Google Switzerland). Also, we cannot claim to truly have had an influence on how Apple developers write their code – this may be the case, or it may not.

What we can claim, however, is that, thanks to TAPS, Apple follows an open standard.

This is officially declared here:
https://github.com/apple/swift-nio-transport-services
"Network.framework is Apple's reference implementation of the proposed post-sockets API that is currently being worked on by the Transport Services Working Group (taps) of the IETF."

5. Sources to corroborate the impact

(alphabetic order)

Anna Brunstrom, Karlstad University, anna.brunstrom@kau.se
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Colin Perkins, University of Glasgow, csp@csperkins.org
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Brian Trammell, Google Switzerland GmbH, ietf@trammell.ch
Éric Vyncke, Cisco Systems, evyncke@cisco.com

UiS_IDE – Impact case 2 - Factiverse - fake news detection

Institution: University of Stavanger
Administrative unit: Department of Computer Science and Electrical Engineering (TN-IDE)
Title of case study: Deep neural networks for fact-checking (Factiverse)
Period when the underpinning research was undertaken: 2017-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2017-2022
Period when the impact occurred: 2020-2022

1. Summary of the impact (indicative maximum 100 words)

Factiverse provides an automated fact-checking system that has impacted the way media content is generated and reported. By providing media companies with advanced, AI-driven tools for verifying information, this initiative has greatly enhanced the accuracy and reliability of news dissemination. The system's ability to quickly and effectively identify false or misleading information has been crucial in combating the spread of misinformation. It has empowered journalists with real-time fact-checking capabilities, enabling more responsible and trustworthy reporting. In addition, Factiverse has made significant contribution to advancement of trustworthy AI and educating students in AI through masters and bachelor students.

2. Underpinning research (indicative maximum 500 words)

This initiative was primarily focused on harnessing the capabilities of automated deep learning methodologies to elevate the process of verifying the factual accuracy of news content. Central to this endeavor was the design and implementation of innovative hierarchical deep attention networks. These deep neural networks were engineered to comprehend and represent various underlying latent aspects of news content through advanced embedding techniques. A distinctive feature of this model was its departure from the traditional approach of word-level self-attention. Instead, it introduced a sophisticated hierarchical structure of attention mechanisms for learning and integrating latent aspect embeddings. These embeddings played a pivotal role in the nuanced classification of false claims, demonstrating remarkable predictive prowess.

To validate and refine the model's capabilities, we employed popular datasets in these areas such as Politifact, Snopes, and FEVER. The empirical evidence gathered from these datasets was compelling, underscoring the superior predictive accuracy of the learned aspect embeddings in identifying false claims. This research not only surpassed the benchmarks set by the state-of-the-art solutions as of 2019, but also garnered prestigious recognition in the form of a US patent. Furthermore, it made significant scholarly contributions, evidenced by multiple publications in leading journals and conferences dedicated to information retrieval.

The far-reaching impact of this research not only resulted in academic achievements but also resulted in practical realization of Factiverse. This spinoff venture was a direct outcome of the groundbreaking work, embodying the transition from theoretical research to tangible, real-world application. Factiverse is a testament to the potential of this academic research that can result in innovation in industry. Factiverse has since developed and deployed several products such as browser plugin, text editor and as a ChatGPT plugin using the deep neural networks developed in this research at their core.

Key researchers involved in this research include Associate Professor Vinay Setty and PhD student Rahul Mishra and masters and bachelor students.

3. References to the research (indicative maximum of six references)

[1] Rahul Mishra and Vinay Setty. “SADHAN: Hierarchical Attention Net- works to Learn Latent Aspect Embeddings for Fake News Detection”. In: Proceedings of the ACM SIGIR International Conference on Theory of Information Retrieval. ICTIR ’19. 2019, pp. 197–204.

[2] Vinay Setty and Erlend Rekve. “Truth be Told: Fake News Detection Using User Reactions on Reddit”. In: Proceedings of the ACM International Conference on Information and Knowledge Management. CIKM ’20. 2020, pp. 3325–3328.

[3] Botnevik, B., Sakariassen, E., & Setty, V. (2020, July). Brenda: Browser extension for fake news detection. In Proceedings of the 43rd international ACM SIGIR conference on research and development in information retrieval (pp. 2117-2120).

[4] Sheikhi, G., Opdahl, A. L., Touileb, S., & Setty, V. (2023). Making Sense of Nonsense: Integrated Gradient-based Input Reduction to Improve Recall for Check-worthy Claim Detection. Proceedings of the 5th Symposium of the Norwegian AI Society (NAIS 2023).

[5] Opdahl, Andreas L., Bjørnar Tessem, Duc-Tien Dang-Nguyen, Enrico Motta, Vinay Setty, Eivind Throndsen, Are Tverberg, and Christoph Trattner. "Trustworthy journalism through AI." Data & Knowledge Engineering 146 (2023): 102182.

[6] Vinay Setty. “Extreme Classification for Answer Type Prediction in Ques- tion Answering”. In: Proceedings of the ACM/IEEE Joint Conference on Digital Libraries, JCDL 2023. JCDL ’23. 2023, pp. 232–236.

4. Details of the impact (indicative maximum 750 words)

The research initiative spearheaded by Associate Professor Vinay Setty, PhD student Rahul Mishra, alongside a talented team of master's and bachelor's students, has led to a profound transformation in the landscape of media integrity and AI education. The development of hierarchical deep attention networks marked a significant departure from conventional word-level self-attention models. This innovative approach to understanding and representing the latent aspects of news content through advanced embedding techniques has been instrumental in the creation and success of Factiverse, an automated fact-checking system.

The research's core was the creation of sophisticated neural networks capable of dissecting and analyzing news content at an unprecedented depth. These networks were not confined to the academic sphere; they became the technological backbone of Factiverse, providing a suite of tools that include a browser plugin, text editor, and a ChatGPT plugin. This technology was rigorously tested and validated using comprehensive datasets such as Politifact, Snopes, and FEVER, ensuring its efficacy and reliability.

Nature and Extent of the Impact:

1. Advancement of AI for Fact-Checking:

The research provided a robust, AI-driven infrastructure that elevated the accuracy of fact-checking processes. Factiverse, harnessing the power of this research, emerged as a pioneering solution in the battle against misinformation, significantly enhancing the quality and reliability of media content.

2. Trustworthy Media and News:
Media companies adopting Factiverse's tools have seen a marked improvement in the accuracy of their reporting. The real-time fact-checking capabilities provided by Factiverse have played a critical role in curtailing the spread of misinformation, fostering a media landscape that upholds truth and transparency.

3. Ease of AI Usage in Media Products and Workflows:
The integration of Factiverse's tools into existing media production workflows has streamlined the process of news verification. Journalists and content creators can now easily incorporate reliable AI-driven fact-checking into their daily routines, enhancing productivity and content quality.

4. Jobs Created:
The commercialization of the research through Factiverse has not only led to the creation of new jobs within the company but also fostered a broader ecosystem of employment opportunities. These roles range from technical positions in AI development to editorial roles in content verification. Currently Factiverse employs 6 full-time employees and 4 past employees who have moved on to more senior roles.

5. Educational Impact:
The project's engagement with master's and bachelor's students has been dual-fold: it has contributed to the advancement of the technology and played a pivotal role in shaping the next generation of AI professionals. Students involved in the project have received hands-on, real-world experience, preparing them for successful careers in the burgeoning field of AI. From 2020-2023, about 30 bachelor and masters University of Stavanger students have successfully finished their thesis and have ended up in jobs such as data scientist in Finn.no, Capgemini, Bouvet, Sopra Steria etc.

6. Research grants:
Factiverse initiative also resulted in several projects from Norwegian Research Council (Forny, IPN) and Innovation Norway (Milestone and innovation contract). Factiverse is also involved in MediaFutures SFI headed by UiB.

Evidence of Impact:

- Factiverse's tools, including the browser plugin, text editor, and ChatGPT plugin, are in active use, demonstrating the practical application and market adoption of the research.w More than 3500 users are currently using these tools.
- Factiverse’s APIs are also integrated into workflows of media companies through CMSs and editors. For example, Wolftech a media workflow planning company has integrated Factiverse APIs in their CMS which is used by media companies such as BBC and CBS.
- Awards and recognition such as the SR-Bank Innovation Prize and the NORA AI Startup Prize underscore the innovative nature and societal relevance of the research.
- Testimonials and case studies from media companies using Factiverse's tools reflect the positive impact on their operations and the broader implications for media integrity.

- The involvement of academic institutions in nurturing the project highlights the educational significance of the research, contributing to the field's knowledge base and training future AI professionals.
- The impact of this research initiative is multifaceted, spanning technological innovation, media integrity, educational advancement, and job creation. Through a seamless blend of rigorous academic research and practical application, Factiverse stands as a testament to the transformative power of AI in fostering a more informed and truthful society.

5. Sources to corroborate the impact (indicative maximum of ten references)

1. Deep neural architectures for detecting false claims VJ Setty, R Mishra US Patent 10,803,387
2. Factiverse products https://editor.factiverse.ai, https://gpt.factiverse.ai
3. SR-Bank innovation prize https://www.uis.no/nb/om-uis/pris-for-teknologi-som-flagger-falske-nyheter
4. NORA AI startup prize https://www.nora.ai/news-and-events/news/nora-annual-awards-winners2023%21.html
5. Digital trust challenge https://www.linkedin.com/posts/kipark_digital-trust-challenge-music-views-by-activity-7062431700420567040-Ym24/?utm_source=share&utm_medium=member_desktop
6. Factiverse-Wolftech partnership https://wolftech.no/factiverse-wolftech-new-partnership-announcement/

UiS_IDE – Impact case 1 - Smartphone use in CPR

Institution: University of Stavanger
Administrative unit: Department of Computer Science and Electrical Engineering (TN-IDE)
Title of case study: Smartphone use in CPR
Period when the underpinning research was undertaken: 2016-2020
Period when staff involved in the underpinning research were employed by the submitting institution: 2016-2020
Period when the impact occurred: 2020-2023

1. Summary of the impact (indicative maximum 100 words)

A collaboration between the University of Stavanger and Laerdal Medical has led to the development of an algorithm that utilizes a smartphone camera to measure the quality of cardiopulmonary resuscitation (CPR) performed provided to a patient. The work started out as a master thesis project in 2016 and was continued as a part of a PhD thesis. The camera algorithm and solution were initially meant for real cardiac arrest cases but has been implemented in training products by Laerdal Medical. By end of 2023 the most popular product the camera algorithm has been implemented in had trained 130 000 people.

2. Underpinning research (indicative maximum 500 words)

In 2016, Laerdal Medical and IDE at the University of Stavanger collaborated on a master thesis to utilize a smartphone camera and image processing techniques to measure CPR quality. Thomas Hinna conducted the project, and the developed algorithm that measured the chest compression rate in real-time was embedded in a smartphone application. Together with his advisor, Kjersti Engan, they also published this work. The purpose of this concept is to provide feedback and guidance to bystanders and emergency dispatchers during real emergencies.

Laerdal Medical recognized weaknesses in the initial algorithm and saw the need to improve it. This led to a collaboration with the University to further develop the solution in Øyvind Meinich-Bache's PhD work. His objective was to improve and optimize the algorithm to address various types of noise that may arise during real emergencies, while also exploring the possibility of measuring chest compression depth using the camera sensor. The outcome of his research was multiple publications, and Laerdal Medical subsequently integrated the finalized algorithm into an app called TCPR link.The concept can be seen here:

https://www.youtube.com/watch?v=EB_Xn3JWXgE

Although the concept of using this technology in real emergencies has not been adopted by any emergency centers, Laerdal Medical recognized its potential for training purposes. When the Covid pandemic arose, there was a need for a tool that would allow CPR facilitators to remotely conduct training sessions for learners worldwide. Transporting manikins to all learners became impractical in such a scenario. As a result, Laerdal Medical, in collaboration with Øyvind Meinich-Bache and the mobile product development team, modified the original solution and application to better suit training scenarios. This involved simplifying the algorithm, as the controlled environments of training sessions differed from real emergency settings. Two products were subsequently launched, both centered around the camera algorithm:

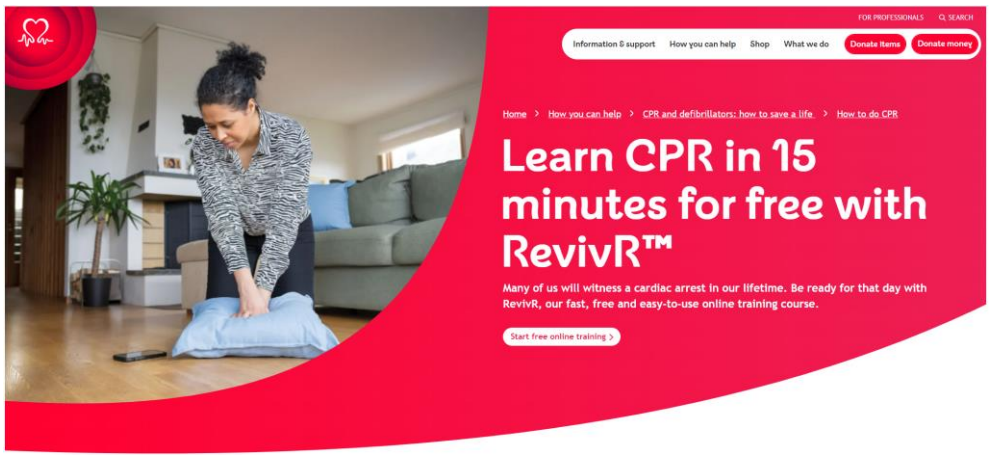
Anniewhere - launched in 2020

https://anniewhere.laerdal.com/

Anniewhere is a web solution that enables instructors to teach CPR skills remotely and in classrooms. Learners join the classroom through a smartphone application called QCPR Classroom, which provide real-time objective feedback to both instructor and learner.

RevivR - launched late 2021.

https://www.bhf.org.uk/how-you-can-help/how-to-save-a-life/how-to-do-cpr/learn-cpr-in-15-minutes



RevivR is a first aid training course originally designed for the community in the United Kingdom. Launched in collaboration with the British Heart Foundation, RevivR consists of three main components: CPR training, AED training, and dispatcher calling training. The CPR training component utilizes the camera detection algorithm, which distinguishes this product from other similar courses. The primary goal of RevivR is to provide affordable training to a wide range of non-professionals globally, enabling as many people as possible to learn these life-saving skills.

Videos:

Concept explanation:
https://vimeo.com/746560656/670f948dc6
Motivation:
https://vimeo.com/699424328

3. References to the research (indicative maximum of six references)

1. Engan, K., Hinna, T., Ryen, T., Birkenes, T. S., & Myklebust, H. (2016). Chest compression rate measurement from smartphone video. Biomedical engineering online, 15(1), 1-19. DOI: 10.1186/s12938-016-0218-6
   First version of the camera algorithm. Mainly developed by Thomas Hinna in his master project at UiS.
2. Meinich-Bache, Ø., Engan, K., Birkenes, T. S., & Myklebust, H. (2017, September). Robust real-time chest compression rate detection from smartphone video. In Proceedings of the 10th International Symposium on Image and Signal Processing and Analysis (pp. 7-12). IEEE.
   DOI: 10.1109/ISPA.2017.8073560
   Øyvind Meinich-Bache continues the work of Thomas Hinna and Kjersti Engan in his PhD. Improved and optimized the algorithm and make it robust against noise.
3. Meinich-Bache, Ø., Engan, K., Birkenes, T. S., & Myklebust, H. (2018). Real-Time chest compression quality measurements by smartphone camera. Journal of healthcare engineering, 2018.
   DOI: 10.1155/2018/6241856
   Demonstrating the camera algorithm`s robustness to noise
4. Meinich-Bache, Ø., Engan, K., Eftestøl, T., & Austvoll, I. (2018, October). Kinect Modelling of Chest Compressions-A Feasibility Study for Chest Compression Depth Measurement Using Digital Strategies. In 2018 25th IEEE International Conference on Image Processing (ICIP) (pp. 913-917). IEEE.
   DOI: 10.1109/ICIP.2018.8451387
   Modelled different bystander CPR techniques using a depth camera sensor and tracking – feasibility study for chest compression depth measurement using digital strategies.
5. Meinich-Bache, Ø. (2020). Automatic Video Analysis in Resuscitation. https://hdl.handle.net/11250/2684476
   Explaining the use case and the methods in PhD thesis of Øyvind Meinich-Bache

4. Details of the impact (indicative maximum 750 words)

Both **Anniewhere** and **RevivR** have gained popularity as training products and programs within Laerdal Medical, with RevivR being the flagship offering. These simple and affordable training programs allow users to learn CPR from anywhere in the world, eliminating the need for costly equipment. Instead of using advanced manikins, the solution enables training with basic non-sensorized manikins or even a pillow for CPR practice. The products leverage the camera algorithm developed by the University of Stavanger, providing users with feedback and guidance on achieving the correct compression rate during chest compressions.

To date, the **Anniewhere** platform has facilitated over 29,000 trainings, with the majority utilizing the camera algorithm for compression rate detection.

sThe RevivR product and program have been launched in various integrations:

Name	**Intended users**	**Country**	**Partner**	**Launch**	**Link**
RevivR Solo	General Public	United Kingdom	British Heart Foundation	December 2021	https://revivr.bhf.org.uk/
RevivR Group	Companies	United Kingdom	British Heart Foundation	October 2022	https://revivr.bhf.org.uk/group

Classroom RevivR	Schools	United Kingdom	British Heart Foundation	September 2023	https://revivr.bhf.org.uk/classroom/group
HLR På 1-2-3	General Public	Norway	Sammen Redder Vi Liv (Helsedirektoratet)	October 2022	https://hlrpa123.113.no/
AllaKanHLR	Schools and general public	Sweden	Swedish Resuscitation Council	September 2023	https://allakanhlr.nu/
Liv Coaching App	General Public	Japan	AED Zaidan	January 2024	https://liv.aed-zaidan.jp/
CPR Anytime Adult/Child	CPR instructors	USA	American Heart Association	February 2024	https://cpranytime.heart.org/
CPR Anytime Infant	CPR instructors	USA	American Heart Association	February 2024	https://cpranytime.heart.org/infant

- In total more than **110 000** learners have completed the entire RevivR courses.
- On average the learners have a confidence of 3 out of 5 when starting the course, and **4.5 out of 5** when they complete it.

5. Sources to corroborate the impact (indicative maximum of ten references)

In addition to the integrations mentioned in the table provided in section 4, and the total number of trained people (130 000 + 29 000), Laerdal Medical has received multiple stories from individuals who have undergone the training and later utilized their skills to save lives. These serve as a testament to the effectiveness and real-world impact of the training. One such story can be found here:

https://www.linkedin.com/posts/british-heart-foundation_restartaheartday-restartaheart-activity-7118246960779702272-4o9-/?utm_source=share&utm_medium=member_desktop

Japan RevivR program on TV news in Japan, 19.01.24
https://www3.nhk.or.jp/tokai-news/20240119/3000033796.html

UiS_IDE – Impact case 3 - EnergiX - Smart Community Neighbourhood

Institution: University of Stavanger
Administrative unit: Department of Computer Science and Electrical Engineering (TN-IDE)
Title of case study: The Smart Community Neighborhood - driven by energy informatics (SmartNaBoEI)
Period when the underpinning research was undertaken: October 2017 -- November 2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2011 -
Period when the impact occurred: October 2017 -- November 2022

1. Summary of the impact (indicative maximum 100 words)

Exploration delved into state-of-the-art Information and Communication Technology (ICT), Artificial Intelligence (AI), and Privacy methodologies, tools, and techniques, envisioning their application in advancing sustainable energy systems. Pioneering the creation of innovative models and algorithms, the aim was to equip power grid operators with intelligent energy management capabilities, all while ensuring privacy at the user level. This project led to the successful completion and defense of dissertations for five Ph.D. students. Additionally, it yielded approximately 30 scientific publications featured in peer-reviewed conferences and journals. The outcomes extended beyond academic recognition, encompassing the successful acquisition of two United States patents, media coverage, and active involvement in two EU H2020 projects.

2. Underpinning research (indicative maximum 500 words)

The research undertaken during the project's duration is segmented into four principal domains, and a summary of key findings is presented below:

1. **Dynamic Machine-Learning Approaches for Data-Driven Energy Informatics (2017–2020):** Investigating energy informatics through dynamic machine-learning methodologies. Explored in a series of scientific papers, the study encompasses various facets of energy informatics, including energy load forecasting and informatics applicability. It delves into the application of deep learning techniques and neural network frameworks. The work culminates in a comprehensive examination of influential factors in short-term energy load forecasting, making a holistic and impactful contribution to the field.
2. **Predictive Analytics for Maintaining Power System Stability (2018–2021):** This research delves into short-term load forecasting and energy forecasting for household communities. The study is encapsulated in a collection of scientific papers investigating aspects such as feature selection methods, smart meter data utilization for load forecasting, accuracy enhancement through load disaggregation techniques, and the introduction of an ensemble approach for multi-step ahead energy forecasting. Multiple publications in conferences and journals underscore the significance of predictive analytics in fortifying the stability of power systems.
3. **Blockchain-Based Energy Transactions for a Prosumer Community (2018–2021):** Exploring innovative energy management approaches within a prosumer community through blockchain technology. The study covers transactive energy using Hyperledger Fabric, renewable energy management through RenewLedger, and a blockchain-based transaction system utilizing fungible and non-fungible tokens for community-based energy infrastructure. The work delves into prosumer incentivization for peak mitigation through

temporal aggregation and contextual clustering, aiming to advance the understanding and application of blockchain in optimizing energy transactions within prosumer communities.

4. **Secure and Privacy-Driven Energy Data Analytics (2019–2022):** This research provides an in-depth exploration of the intersection of blockchain technology, big data analytics, and artificial intelligence within the context of energy smart grids. Supported by a series of scientific papers, including works on the "TOTEM" framework, the study incorporates blockchain for controlled computation, distributed computational architectures, and methods for data analysis. Emphasizing the integration of big data and blockchain in the TOTEM framework, the work significantly contributes to understanding secure decentralized computation, particularly focusing on the application of artificial intelligence. The compilation of scientific papers, disseminated across multiple conferences and journals, reflects noteworthy contributions to the evolving landscape of energy data analytics and secure computation.

The following enumerates the primary researchers engaged in the project along with their respective roles during the project period:

- Dhanya Therese Jose (PhD Student; successfully completed)
- Nikita Rajendra Karandikar (PhD Student; successfully completed)
- Aida Mehdipour Pirbazari (PhD Student; successfully completed)
- Cristina Viorica Heghedus (PhD Student; successfully completed)
- Rituka Jaiswal (PhD Student; successfully completed)
- Antorweep Chakravorty (Associate Professor; Work package leader)
- Chunming Rong (Professor)

3. References to the research (indicative maximum of six references)

This section highlights key works from the identified research domains from the previous section.

- Dynamic Machine-Learning Approaches for Data-Driven Energy Informatics
  - Heghedus, Cristina, Antorweep Chakravorty, and Chunming Rong. "Energy load forecasting using deep learning." 2018 IEEE International Conference on Energy Internet (ICEI). IEEE, 2018. [https://ieeexplore.ieee.org/document/8403442]
- Predictive Analytics for Maintaining Power System Stability
  - Mehdipour Pirbazari, Aida, et al. "Short-term load forecasting using smart meter data: A generalization analysis." *Processes* 8.4 (2020): 484. [https://www.mdpi.com/2227-9717/8/4/484/pdf]
  - Pirbazari, Aida Mehdipour, Antorweep Chakravorty, and Chunming Rong. "Evaluating feature selection methods for short-term load forecasting." *2019 IEEE International Conference on Big Data and Smart Computing (BigComp)*. IEEE, 2019. [https://ieeexplore.ieee.org/document/8679188/]
  - Pirbazari, Aida Mehdipour, et al. "An ensemble approach for multi-step ahead energy forecasting of household communities." IEEE Access 9 (2021): 36218-36240. [https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=9366871]
- Blockchain-Based Energy Transactions for a Prosumer Community
  - N. Karandikar, A. Chakravorty, C. Rong. "Blockchain based transaction system with fungible and non-fungible tokens for a community-based energy infrastructure," in Sensors, vol. 21, no. 11, pp. 3822, 2021. [https://www.mdpi.com/1424-8220/21/11/3822]
  - Karandikar, N., A. Chakravorty, C. Rong. "Blockchain-based prosumer incentivization for peak mitigation through temporal aggregation and contextual clustering," in Blockchain: Research and Applications, vol. 2, no. 2, pp. 100016, 2021. [https://www.sciencedirect.com/science/article/pii/S2096720921000117]

- Secure and Privacy-Driven Energy Data Analytics
    - Jose, Dhanya Therese, Antorweep Chakravorty, and Chunming Rong. "Totem: Token for controlled computation: Integrating blockchain with big data." *2019 10th International Conference on Computing, Communication and Networking Technologies (ICCCNT)*. IEEE, 2019. [https://www.researchgate.net/profile/Dhanya-Jose/publication/338361568_TOTEM_Token_for_controlled_computation_Integrating_Blockchain_with_Big_Data/links/5fd8821492851c13fe894dfb/TOTEM-Token-for-controlled-computation-Integrating-Blockchain-with-Big-Data.pdf]
    - Jose, Dhanya Therese, Chunming Rong, and Antorweep Chakravorty. "Application of artificial intelligence in secure decentralized computation enabled by TOTEM." 2022 IEEE Asia-Pacific Conference on Computer Science and Data Engineering (CSDE). IEEE, 2022. [https://ieeexplore.ieee.org/abstract/document/10089248]

4. Details of the impact (indicative maximum 750 words)

The project has made a transformative impact by advancing the forefront of Information and Communication Technology (ICT), Artificial Intelligence (AI), and Privacy methodologies within the context of sustainable energy systems. Pioneering innovative models and algorithms, it has empowered power grid operators with intelligent energy management capabilities while safeguarding local privacy. The project's influence is multifaceted, extending across academic, industrial, and societal realms.

Academic and Research Impact:

1. Dissertations and Publications: The project led to the successful completion and defense of five Ph.D. theses, demonstrating its academic depth. Approximately 30 scientific publications, disseminated in peer-reviewed conferences and journals, underscore the project's scholarly contributions.
2. Patents: The acquisition of two United States patents solidifies the project's innovative impact. "Method for Analyzing Data Using a Blockchain" (US Patent 1112187, 2019) and "User Controlled, Decentralized, Distributed, and Secure Content Distribution," (US Patent 11113410, 2018) validates the project's innovative methodologies. These enduring patents offer practical frameworks for secure data analysis and user-controlled content distribution, reflecting the project's commitment to advancing theoretical understanding and real-world applications.
3. EU Horizon 2020 Projects: Research outcomes of the project influanced two EU H2020 projects, namely TradeRES (grant agreement number: 864276, 2020-2024) and ARTICONF (grant agreement number: 825134, 2019 - 2022). It exemplifies the project's practical contributions, shaping the future landscape of renewable power systems and social media ecosystems.

Research Contributions in Information Technology:

1. Blockchain-Based Innovations: The development of "Ushare," a user-controlled social media platform (2017), and the integration of blockchain for multilevel data sharing and transactive energy transactions showcase the project's impact on decentralized and secure data management (2018).
2. Deep Learning for Energy Load Forecasting: The application of deep learning techniques for energy load forecasting, presented in IEEE conferences (2018-2021), contributes significantly to advancements in predicting energy loads, with implications for enhancing energy management systems.
3. Predictive Analytics for Energy Consumption: Pioneering contributions to predictive analytics for household energy consumption, including EV charging demand prediction (2018) and ensemble neural networks (2018-2021) for power demand and peak prediction, reflect the project's impact on more accurate and efficient energy consumption predictions.

4. TOTEM Framework: The creation of the "TOTEM" framework (2019), integrating blockchain for controlled computation, represents a breakthrough in secure decentralized computation. Its presentation in various IEEE conferences (2019-2022) reflects a commitment to advancing the understanding and application of blockchain technology in energy systems.

Practical Applications and Tools: RenewLedger (2020) and TOTEM SDK (2021) - The creation of practical tools such as RenewLedger for renewable energy management and TOTEM SDK as an open toolset for token-controlled computation translates research outcomes into tangible solutions, adding a practical dimension to transformative outcomes.

Media Coverage: The project's impact is further accentuated by coverage in popular media articles, bridging technical advancements with broader societal implications. Articles in coinfomania.com (2020), aftenbladet.no, (2019), and digitalnorway.com(2021) contribute to public awareness, fostering a greater understanding of the research's potential applications and societal benefits.

In conclusion, the cumulative impact of this research spans advancements in energy system decentralization, energy load forecasting, predictive analytics for household energy consumption, blockchain-enabled data security, and the development of practical tools for energy management. These contributions collectively underscore the transformative potential of technology in shaping a more efficient, secure, and decentralized future for information and energy systems.

5. Sources to corroborate the impact (indicative maximum of ten references)

1. Estanqueiro, Ana, et al. "Innovative electricity market designs to support a transition to (near) 100% renewable power system: first results from H2020 TradeRES project." (2023): 274-281.
2. Dhanya Therese Jose "Secure and Privacy Driven Energy Data Analytics. In PhD thesis UiS; 673, Published by University of Stavanger, Norway, 2022." (2022). [uis.brage.unit.no/uis-xmlui/handle/11250/3031051]
3. Jose, Dhanya Therese, Antorweep Chakravorty, and Chunming Rong. "Method for analyzing data using a blockchain, a data provider and a data customer therefor." U.S. Patent No. 11,121,874. 14 Sep. 2021.
4. Chakravorty, Antorweep, and Chunming Rong. "User controlled, decentralized, distributed, and secure content distribution." U.S. Patent No. 11,113,410. 7 Sep. 2021. APA
5. Behzad, Behfar, et al. "TOTEM SDK: an open toolset for token controlled computation managed by blockchain." *2021 IEEE Asia-Pacific Conference on Computer Science and Data Engineering (CSDE)*. IEEE, 2021.
6. Nikita Karandikar " Blockchain based energy transactions for a prosumer community. In PhD thesis UiS; 599, Published by University of Stavanger, Norway, 2021." (2021). [uis.brage.unit.no/uis-xmlui/handle/11250/2776481]
7. Aida Mehdipour Pirbazari " Predictive Analytics for Maintaining Power System Stability in Smart Energy Communities. In PhD thesis UiS; 587, Published by University of Stavanger, Norway, 2021." (2021). [https://uis.brage.unit.no/uis-xmlui/handle/11250/2755369]
8. Secure, Controllable, Decentralized Data Sharing: published by coinfomania.com on 7th April 2020. [https://coinfomania.com/interview-with-bityoga-ceo-antorweep-chakravorty/]
9. Karandikar, Nikita, Antorweep Chakravorty, and Chunming Rong. "RenewLedger: Renewable energy management powered by Hyperledger Fabric." 2020 IEEE symposium on computers and communications (ISCC). IEEE, 2020.
10. Prodan, Radu, et al. "ARTICONF: towards a smart social media ecosystem in a blockchain federated environment." *European Conference on Parallel Processing*. Cham: Springer International Publishing, 2019.

University of Stavanger, Department of Energy & Petroleum Engineering

Case 1

Institution: University of Stavanger
Administrative unit: Department of Energy and Petroleum Engineering (TN-IEP)
Title of case study: New Cementitious Material for Oil Well Cementing Applications - SafeRock
Period when the underpinning research was undertaken: 2021 - 2024
Period when staff involved in the underpinning research were employed by the submitting institution: 2018 -
Period when the impact occurred: 2022 - 2024

1. Summary of the impact (indicative maximum 100 words)

UiS has developed a material technology which has 90% lower CO2 emission than Portland cement used in the oil & gas industry and in the construction industry. If adapted globally by the oil & gas industry, the CO2 reduction will be 26 mega tonnes annually. The technology is currently at technology readiness level 5 and further developments are ongoing.

The project has in addition contributed to knowledge development in the fields of geopolymer chemistry, well abandonment and well integrity.

2. Underpinning research (indicative maximum 500 words)

The research undertaken during the project's duration can be divided into four different topics segmented into four principal domains, and a summary of key findings is presented below:

1. **Do wellbore geometry and mud contamination affect displacement of the geopolymers?**
   The viscous properties of geopolymers have been compared to those of well cement slurries. Also, the effect of mud contamination on the rheology profile and the displacement process have been researched and better understood.
2. **Is it possible to make flexible geopolymers for downhole applications?**
   Portland cement is a brittle material and vulnerable to tectonic movements and stress changes. Geopolymers is a more ductile material, and the project has investigated the tradeoff between ductility and strength by using inorganic polymer chemistry and experimenting with a variety of additives.
3. **Is it possible to use geopolymers for cold area applications?**
   The cementing of conductor and surface casing requires the zonal isolation material to set at low temperatures. Cement has limitations for use in near seabed or surface where temperature is relatively low, which is common in petroleum producing regions such as North Sea, Alaska, Russia, GOM, etc. Long wait on cement setting time which may cause well integrity issues are examples of challenges. The project has developed geopolymers that set much faster than cement under these conditions.
4. **Is there any knowledge gap from lab scale to full-scale testing?**
   Two full scale tests were performed at Ullrigg at NORCE by using identical equipment as being used for cementing operations. The first test was a failure, but the results from this were used to design a successful second test demonstrating that geopolymers in full scale are equally good as cement.

The following enumerates the primary researchers engaged in the project along with their respective roles during the project period:

- Mahmoud Khalifeh (Professor, project leader)
- Arild Saasen (Professor, advisor)
- Øystein Arild (Head of Department, WP leader)
- Saeed Salehi (Associate Professor, Oklahoma University, USA, WP leader)
- Ian Frigaard (Professor, University of British Columbia, Canada, WP leader)
- Amir Taheri (Researcher, NORCE, WP leader)
- Fawzi Chamssine (PhD Student; successfully completed)
- Mohammed Omran (PhD Student; successfully completed)
- Foster Gomado (PhD Student; on schedule)
- Pouya Khalili (PhD Student; on schedule)
- Mohammadreza Kamali (PostDoc researcher)
- Several master students as assistants

- **References to the research** (indicative maximum of six references)

This section highlights key works from the identified research domains from the previous section.

- Gomado, F.D., Khalifeh, M., Saasen, A., Kjøniksen, A.L., Sanfelix, S.G., and Aasen, J.A. 2023. Effect of Calcium Expansive Additives on the Performance of Granite-Based Geopolymers for Zonal Isolation in Oil and Gas Wells. SPE journal SPE-217431-PA. https://doi.org/10.2118/217431-PA
- Hoayek, A., Khalifeh, M., Hamie, H., El-Ghoul, B., and Zogheib, R. 2023. Prediction of geopolymer pumpability and setting time for well zonal isolation - Using machine learning and statistical based models. Heliyon Journal. https://doi.org/10.1016/j.heliyon.2023.e17925
- Omran, M., Hjelm, S., Khalifeh, M., and Salehi, S. 2023. Synthesis of Sustainable One-Part Geopolymers for Well Cementing Applications. Journal of Geoenergy Science and Engineering. https://doi.org/10.1016/j.geoen.2023.211822
- Chamssine, F., Gasparotto, L. H.S., Souza, M.A.F., Khalifeh, M., and Freitas, J.C.O. 2022. Retarding mechanism of Zn2+ species in geopolymer material using Raman spectroscopy and DFT calculations. Scientific Reports volume 12, 21036 (2022). https://doi.org/10.1038/s41598-022-25552-0
- Omran, M., Pavia, M.D.M., and Khalifeh, M. 2023. Design and Early Age Performance of Sustainable One-Part Geopolymers for Well Cementing. SPE journal, SPE-215825-PA. https://doi.org/10.2118/215825-PA
- Hajiabadi, S.H., Khalifeh, and van Noort, R. 2023. Multiscale insights into mechanical performance of a granite-based geopolymer: Unveiling the micro to macro behavior. Geoenergy Science and Engineering 231 (2023) 212375. https://doi.org/10.1016/j.geoen.2023.212375

4. Details of the impact (indicative maximum 750 words)

The project has made a transformative impact by advancing the use of new materials for permanent plugging of oil & gas wells as well bringing forward a material that can be a game changer for the global construction industry in terms of reduced CO2 emissions and circular economy. Advancements have been made both in terms of the material properties itself as well as the ability to place the material in a well in conditions where the geometry is not well known and where contamination and pressure and temperature effects may take place.

Academic and Research Impact:

1. Dissertations and Publications: The project led to the successful completion and defense of two completed and two planned Ph.D. theses and one PostDoc, demonstrating its academic depth. Approximately 45 scientific publications, disseminated in peer-reviewed conferences and journals, underscore the project's scholarly contributions, and BSc and MSc projects.
2. Patents: One patent granted, one filed, one under submission
3. Spinoff projects: CEMENTEGRITY (ACT3, led by IFE), WELLFATE (RCN KPN, led by IFE), SWIPA (RCN SFI, led by Sintef), MGeo (RCN IPN, led by SafeRock AS), Solidrock (RCN IPN, led by SafeRock AS).
4. Increased international collaboration in Brazil, Japan and USA; PUC and UFRJ in Rio de Janeiro, Hokkaido University and Oklahoma State University.

Practical Applications and Tools: the technology can be used in the field of petroleum industry and civil engineering. A successful full-scale test has been conducted at Ullrigg NORCE, where a 9 m geopolymer plug was compared head-to-head with a 9 m Portland cement plug, concluding that the geopolymer plug was equally good as the cement plug. The current TRL level is 5.

Media Coverage:

https://www.tu.no/artikler/na-kommer-losningen-som-erstatter-sement-utslippsfri-herder-i-kulda-og-takler-fukt/515116
https://www.valide.no/aktuelt/veidekke-vil-bruke-saferock-betong
https://www.arkitekturnytt.no/2022/02/brekraftig-alternativ-til-sement.html
https://no.linkedin.com/posts/university-of-stavanger_equinor-investerer-i-betong-startup-activity-6963384277753372674-HIXR
https://e24.no/energi-og-klima/i/XqvE9o/equinor-inn-paa-eiersiden-i-betongselskapet-saferock
https://www.upstreamonline.com/upstreamtechnology/building-blocks-for-better-cement/2-1-241111

5. **Sources to corroborate the impact** (indicative maximum of ten references)

1. Raymos Kimanzi, Yuxing Wu, Saeed Salehi, Mehdi Mokhtari, Mahmoud Khalifeh. 2020. Experimental Evaluation of Geopolymer, Nano-Modified, and Neat Class H Cement by Using Diametrically Compressive Tests. J. Energy Resour. Technol. Sep 2020, 142(9): 092101 (7 pages). Paper No: JERT-19-1780 https://doi.org/10.1115/1.4046702
2. E. Eid; H. Tranggono; M. Khalifeh; S. Salehi; A. Saasen. 2021. Impact of Drilling Fluid Contamination on Performance of Rock-Based Geopolymers. SPE J. 26 (06): 3626–3633. Paper Number: SPE-205477-PA. https://doi.org/10.2118/205477-PA
3. Mohammadreza Kamali, Mahmoud Khalifeh, Arild Saasen, Rune Godøy, Laurent Delabroy. 2021. Alternative setting materials for primary cementing and zonal isolation – Laboratory evaluation of rheological and mechanical properties. Journal of Petroleum Science and Engineering 201 (2021) 108455. https://doi.org/10.1016/j.petrol.2021.108455

[UIS_IMBM] [IMPACT CASE_1]

Institution: *University of Stavanger*
Administrative unit: *Department of Mechanical and Structural Engineering, and Materials Science (IMBM)*
Title of case study: *Search and rescue in Polar Waters - SARex*
Period when the underpinning research was undertaken: *2016-2020*
Period when staff involved in the underpinning research were employed by the submitting institution: *Professor Ove Tobias Gudmestad 2012 – 2018 (2018-2020 Professor Emeritus)* *PhD-candidate K.E. Solberg 2015 - 2020*
Period when the impact occurred: *2016-2020*

1. **Summary of the impact**

The SARex project involved researchers, industry, equipment-manufacturers, and authorities, and aimed to carry out search and rescue exercises in the Artic.
Emphasis was on rescue-equipment and survival. Standard SOLAS rescue-equipment was tested, with the conclusion that the equipment would not be sufficient to fulfil IMO Polar Code requirements. Additionally, the capacity of rescue helicopters was found to be insufficient.
The main impacts of SARex were the rapid inclusion by IMO (2019) of the main findings through interim guidelines for life-saving appliances and arrangements for ships operating in polar waters. The SOLAS Convention document was updated with new requirement for ventilation.

2. Underpinning research (indicative maximum 500 words)

The introduction of the Polar Code, and particularly the requirement for a minimum of five-day survival onboard lifeboats and life rafts, spurred the Universities of Stavanger and Tromsø to join the Norwegian Coast Guard to carry out search and rescue exercises in the waters off Svalbard at 80 degrees north, from 2016 to 2018.

Several rescue missions in the Arctic decades before the SARex project showed the need for additional requirements with respect to search and rescue equipment in Arctic waters. The aim of the project was to identify and explore the gaps between the functionality provided by the existing SOLAS (International Convention for Safety of Life at Sea) approved safety-equipment and the functionality required by the IMO (International Maritime Organization) Polar Code.

The SARex exercises involved researchers, industry, and equipment manufacturers, as well as authorities. Of particular value was the participation of the Norwegian Maritime Authority. The ice-strengthened Coast Guard vessel KV Svalbard was used for the exercises, also providing training for the personnel on board, another welcomed impact of the project. During the 2016 SARex, standard SOLAS rescue-equipment was tested, with the conclusion that the equipment would not be sufficient to fulfil the IMO Polar Code requirements. Improved equipment was tested in 2017, with the conclusion that smaller improvements gave huge benefits. The key improvements were:

• for the life-raft, the bottom of the raft had a double layer to protect the rescued from the cold water below. The raft was also taller, to allow people to stand up, and the ventilation was improved.

• for the lifeboat, the seats were equipped with insulation, the heating and ventilation were improved and there was more space to move around.

During the expeditions, of particular concern was the rapid build-up of CO_2-concentration within the rescue-means and the need for more calories and water than prescribed by SOLAS. In this respect, it should be noted that energy is needed to keep the body warm in a cold environment.

Another finding was the low capacity of rescue helicopters: Insufficient in a mass rescue situation. SARex 2018 was carried out to test personal protective and group protective equipment packages provided by the industry. Large deviations between the quality of the equipment were evident. The main benefits of the SARex exercises were the rapid inclusion by the IMO in 2019 of the main findings of the exercise through new interim guidelines for life-saving appliances and arrangements for ships operating in polar waters. This was made possible through the participation of the Maritime Authority of Norway in IMO-committees and the availability of the SARex reports.

The participants in this project included Norwegian and Canadian Universities, as well as hospitals, Norwegian Defense Forces and Norwegian Authorities. From UiS' side the main participants were Professor Ove Tobias Gudmestad, project manager, PhD-fellow Knut Espen Solberg. Professor Ove Njå and professor Bjørn Ivar Kruke, UiS, also took part in the project, but are not employed by the unit IMBM. Following the project, Espen Engtrø (UiS) used the material collected from the SARex exercises for his PhD studies.

3. References to the research (indicative maximum of six references)

The SARex project produced 3 project reports available here:
SARex1: https://uis.brage.unit.no/uis-xmlui/handle/11250/2414815

SARex2: https://uis.brage.unit.no/uis-xmlui/handle/11250/2468805
SARex3: https://uis.brage.unit.no/uis-xmlui/handle/11250/2578301

Two PhD-theses wer produced as a result of the project:
PhD Thesis:
Solberg, K-E: Safety and Emergency Response Associated with Cold Climate Marine Operations, PhD thesis UiS, no. 493, 2020.
Engtrø, E: The implementation and application of the International Code for Ships Operating in Polar Waters (Polar Code): Evaluations and considerations addressing this function-based regulation's effect on safety and emergency preparedness concerning Arctic shipping. PhD thesis UiS, no. 618, 2021.

Additionally, the project produced a series of published articles listed in:

Gudmestad, OT: Recent Norwegian Research relevant for Evacuation, Search and Rescue under Arctic Conditions, IOP Conf. Ser.: Earth Environ. Sci. 987 012005, 2022.

Key articles are listed below:
Gudmestad, OT, and Solberg K-E: Findings from Two Arctic Search and Rescue Exercises North of Spitzbergen. Polar Geography published online March 2019.
http://dx.doi.org/10.1080/1088937X.2019.1597394.

Jensen, JE, Solberg, KE, and Gudmestad, OT: Survival in cold waters - learnings from participation in cold water exercises - a regulatory perspective related to the Norwegian offshore industry. IOP

Conference Series: Materials Science and Engineering 2019; Volume 700, Stavanger, November 2019.

Solberg, KE, Jensen, JE, Barane, E., Hagen, S, Kjøl, A, Johansen, G, and Gudmestad, OT: Time to Rescue for Different Paths to Survival Following a Marine Incident, J. Mar. Sci. Eng. 8(12), 997; https://doi.org/10.3390/jmse8120997 (registering DOI), 2020.

Engtrø, E, Gudmestad, OT, and Njå, O: Implementation of the Polar Code: Functional Requirements Regulating Ship Operations in Polar Waters. Arctic Review, 11, 47-69. https://doi.org/10.23865/arctic.v11.2240, 2020.

Engtrø E, Gudmestad OT, and Njå O: The Polar Code's Implications for Safe Ship Operations in the Arctic Region. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation, Vol. 14, No. 3, doi:10.12716/1001.14.03.18, pp. 655-661, 2020.

4. Details of the impact (indicative maximum 750 words)

The SARex project was funded by the project partners and had a total budget estimated to 50 MNOK (including 3-weeks use of the Coast Guard vessel KV Svalbard). PhD student K. E. Solberg was partially funded by NRC (Industrial PhD). One of the major strengths of the project was the size and span of the collaborative network. The partners had a multi-disciplinary approach, and the nature of the consortium formed a basis for common goals and short distance to implementation.

As described, main outcome of the project was the three SARex reports which were used by the national and international authorities to update the then current regulations. As the Maritime Authority of Norway was a partner in the project, the findings were taken into use through participation in IMO-committees and used by the Norwegian Ministry of Trade, Industry and Fisheries.

The activity in polar waters has increased, and several rescue missions in the Arctic have proved the necessity to dig deeper into this topic. The fact that tourism in the Arctic has also increased, led to a need to secure that the regulations also covered possible rescue missions including mass-evacuation, search, and rescue.

The project produced a high amount of data which was processed and used for both academic articles and directly by the authorities to promote the additional requirements for search and rescue in polar waters and focusing on the need for preparedness in case of larger emergencies.

The project caused a direct change in the Polar Code by IMO, which regulates ships operating in polar waters. The findings were also implemented into the International Convention for Safety of Life at Sea (SOLAS), regulating safety within shipping. Available online presentations by both the Norwegian Ministry of Trade, Industry and Fisheries, the Maritime Authority of Norway, and SOLAS shed light on how the data was used and implemented (See references below in chp 5)

The multi-disciplinary approach of the missions allowed for gaining experiences within not only search and rescue, but also within first-response guidelines for medical-teams working in polar environment, risk- and safety-views for operating in the Arctic, as well as practical development of equipment and solutions. As the project included several groups of scientists, and with different nationalities, as well as persons representing authorities and industry, the project also is a good example on how collaboration across borders and disciplines can lead to rapid implementation and benefit for the society in general.

5. Sources to corroborate the impact (indicative maximum of ten references)

Norwegian Maritime Authority:
https://www.sdir.no/sjofart/fartoy/fartoystyper/passasjerskip/svalbard/
https://www.sdir.no/en/shipping/vessels/vessel-types/passenger-vessels/rules-for-passenger-ships-on-svalbard/

Norwegian Ministry of Trade, Industry and Fisheries:
https://www.pame.is/images/03_Projects/Arctic_Marine_Shipping/Polar_Code/Presentations/Siv_Christin_Gaalaas.pdf

http://phys.org/news/2016-05-evacuation-arctic.html
https://www.nord.no/no/aktuelt/nyheter/Sider/Revisiting-the-SARex-Exercise.aspx
http://adac.uaa.alaska.edu/css/images/pdf/SARStateoftheScience_14June2016.pdf
Frontier Energy, Summer 2016 by Frontier Energy - Issuu (Page 18 and 19)
ABS, partners test Polar Code requirements through search and rescue exercise offshore Norway - Drilling Contractor
Field exercises test Arctic survival readiness (worldoil.com)

[UIS_IMBM] [IMPACT CASE_2]

Institution: University of Stavanger
Administrative unit: Department of Mechanical and Structural Engineering and Materials Science
Title of case study: Applied 3D Printing in medical science
Period when the underpinning research was undertaken: 2020 - present
Period when staff involved in the underpinning research were employed by the submitting institution: 2021 – present Hirpa Gelgele Lemu 2002 - present Prof Vidar F. Hansen: 2000 - present Mona W. Minde: 2017 – present Dena Khazeni 2021 - present Yosef Wakjira Adugna 2021 - present
Period when the impact occurred: 2021 - present

Summary of the impact (indicative maximum 100 words)

The units focus on additive manufacturing have produced positive impact within medical sciences. One project (MetAMeT) aims to investigate remplacement of cast implants and medical prostheses with parts produced by additive manufacturing (AM). The knowledge and instruments from the project have been used to produce implants for Indian patients, suffering from black fungus, after covid-19 infection. The patients are treated free of cost at the local hospital in Chennai, India. Another project is working closely with orthopedics to use AM for visualization and preparation for hip-surgery, where the approach is related to the surgeons understanding of the fracture.

1. Underpinning research (indicative maximum 500 words)

The MetAMeT-project concerning AM printed implants and medical prostheses is a bilateral project together with the Indian Institute for Technology Madras, IITM, in Chennai India, the Nordic Institute of Dental Materials (NIOM), Norway, and Advanced Research Centre for Powder Metallurgy and New Materials (ARCI), India. The motivation is to use the new possibilities of 3D-printing in medical treatment where custom-made, print-on-demand components with state-of-the-art properties are made available for prostheses and implants needed in dental restoration and reconstructive surgery following severe trauma or illness. The project investigates mechanical and microstructural properties of CoCrMo/Fe alloys when additively manufactures compared to casted samples. The project has investigated the process and optimizing printing parameters. This has led to extensive knowledge and infrastructure for Metal Additive Manufacturing (MAM). IITM, India, has invested in printers for metal-printing based on Selective Laser Melting (SLM).

The replacement of traditional production processes and materials for implants and prostheses by MAM has advantages in several areas: Economical/environmental: Reducing the material need, thus the costs and energy use. Health: Providing easier accessible and customized prostheses and implants, and Societal: Reducing the use of cobalt in the used alloys, where extraction is conflictual, and the supply is restricted.

MetAMeT work towards increasing the fundamental knowledge about solid-state reactions in MAM which will also be useful in other industries. MAM processes enables, print-on-demand, which may reduce the need for production of unused spare parts, reducing costs, material use, energy, and space. It is particularly the up-skilling in the research-field, along with available infrastructure and multi-disciplinary approach that has enabled the outcomes described here.

The research is carried out by the projects PhD-candidates, Dena Khazeni (UiS) and Jag Parvesh Dahyia (IITM) in collaboration with senior researchers: Professor Vidar Hansen, Dr. Wakshum

Tucho, Dr. Mona Minde (UiS), Dr. John Tibballs (NIOM), and Associate professor Murugaiyan Amirthalingam (IITM). The project started in 2020, and the impact to society has taken place from 2021/2022.

The project "3D printing for surgical planning – Visualization of Hip Fractures" aims at proposing a framework for the visualization of femoral fractures from medical imaging to ready 3D print, with the assumption that a better visualization of a complex fracture will lead to a more accurate fracture classification which determines surgical strategy. X-ray images will show all fragments projecting in an overlapping view, making it challenging for the surgeons to visualize this in the correct three-dimensional structure based on two-dimensional images, and a physical 3D printed model will further improve upon the surgical planning. This project is a collaborative effort together with Stavanger University Hospital. This is a case study where we are visualizing all the steps needed to implement 3D printing in a fast-track procedure. We see this as an important description which will work as a guide for any other cases where 3D printing can be used for surgical planning. The research in this project is produced by PhD-candidate Yosef Wakjira Adugna in collaboration with Professor Hirpa Lemu (IMBM) and Associate professor Hanne Hagland (UiS).

3. References to the research (indicative maximum of six references)

Both projects are driven by the PhD-candidates and there is not yet a large amount of publication on the subject. However, there are some presentations that have been done, and copies of the poster can be sent by the unit to the committee if needed.

Dena Khazeni and Vidar Folke Hansen:
Comparative analysis of Co-Cr-Fe-Mo alloy fabricated by Laser Powder Bed Fusion and casting for dental and maxilla facial application, 2023, poster presentation, The 20th International Microscopy Congress September 10-15, Busan, South Korea

Yosef Wakjira Adugna, **Heinrich Brüggemann, Erik Hafnor, Ane Djuv, Aksel Paulsen, Hanne Røland Hagland, Hirpa Gelgele Lemu:**
A framework for the visualization of femoral fractures from Imaging to 3D Print, 2023, poster presentation, National Conference for Additive Manufacturing, Trondheim, Norway

4. Details of the impact (indicative maximum 750 words)

An outcome of the Covid-19 pandemic was a severe increase in mucormycosis (black fungus) with Indian patients hospitalised with covid-infection and treated with steroids. The ongoing project at IITM and UiS and the collaboration with Fortis Hospital led to the #Right2Face initiative, using the knowledge and infrastructure from the MetAMeT project to provide free 3D-Printed face-implants to patients disfigured by mucormycosis. The illness cannot be treated by medication and the only option is to remove the infected facial bones. The initiative use known and approved alloys to print the missing parts of the scull, helping poor patients to a new life.
As the problem with mucormycosis evolved in hospitals in India around 2021, the researchers in the project were already in contact with surgeons working with facial reconstruction and had developed knowledge and bought infrastructure enabling printing of facial implants. The problems with the fungal infections were mostly present in the poorer part of the population, which does not have the economic power to pay for costly treatment. As the only treatment is removal of the infected bones, untreated patients have severe trouble such as lack of chewing food, talking, problems with sight and breathing, and in general large degrees of disfigurement. Offering

treatment for free as an additional outcome of the MetAMeT project is therefore an initiative to be part of for the research-group.
Adding on to this activity in the research-group in the unit, is the activity in close collaboration with Stavanger University Hospital where the team has developed a process where 3 dimensional CT-images are printed into physical 3D models to improve the understanding of complex femur fractures. The type of fracture has impact on the operating procedure and time is of the essence to initiate treatment as soon as possible, as these particular fractures should be surgically corrected within 24 hours of arrival at the hospital to minimize complications.
The project is still under development, and the process has not yet been used in the hospital. However, the advances are related to the research the unit has on AM, and the way the project has developed the procedures in collaboration with medical practitioners is an impact, not within the physical development, but in how the trans-disciplinary collaboration has succeeded in solving a problem and devise a procedure that improves patient care and treatment. The group is now working on new procedures for visualisation which will be used for used for training of medical students before they get to do actual spinal punctures on patients. This will increase the confidence and accuracy of the medical students when performing these procedures.

5. Sources to corroborate the impact (indicative maximum of ten references)

https://www.thebetterindia.com/339541/iit-madras-chennai-startup-3d-printing-technology-free-face-implants-for-the-poor-patients/

https://www.wionews.com/videos/3d-printed-face-implants-for-face-disfigurement-for-black-fungus-patients-world-dna-673886

https://www.wionews.com/videos/iit-madras-researchers-develop-3d-printed-face-implants-for-black-fungus-patients-674143

[UiS_IMBM] [IMPACT CASE_3]

Institution: University of Stavanger
Administrative unit: Department of Mechanical and Structural Engineering, and Materials Science
Title of case study: Future Energy Hub (FEH)
Period when the underpinning research was undertaken:
Period when staff involved in the underpinning research were employed by the submitting institution: Knut Erik Teigen Giljarhus: 2014 – present (Associate professor) Trond-Ola Hågbo: 2018 - 2023 (PhD-candidate) Siri M. Kalvig: 2009-2014 (Industrial PhD) and 2018 – 2020 (Associate professor) Helleik L. Syse: 2017 – 2018 (researcher)
Period when the impact occurred:

1. **Summary of the impact** (indicative maximum 100 words)

Future Energy Hub (FEH) is a project funded by NFR, Rogaland County Municipality, local industry and UiS. The project acts as a link between different disciplines, and by combining cutting-edge expertise from several fields, a basis is created for cutting-edge innovation and development towards greener cities.

Future Energy Hub has set up an energy-laboratory at UiS to increase expertise within renewable energy and energy efficiency. The aim is to accelerate the development of green technology and services. The business community is actively involved in the projects, and researchers and students at UiS follow pilot projects run by the industry.

2. Underpinning research (indicative maximum 500 words)

The aim of the project is to create greener buildings and neighborhoods in collaboration with industry and the public sector. FEH is a collaboration between 5 departments at the Faculty of Science and Technology, working together with representatives from The Faculty of Social Sciences and Faculty of Arts and Education from UiS, together with Rogaland County Municipality and local industry.

The focus is to use a multidisciplinary approach to solve specific tasks in pilot-projects initiated by the industry. The project also forms a network for collaboration and has 7 PhDs and 2 Postdocs performing their research within the group.

The network runs the energy-lab on campus, and in spring 2019, a wind turbine was lifted into place and installed to complement the solar cells which were already installed. The turbine and solar cells are part of a laboratory that will produce energy from the sun and wind. Students, researchers, and businesses have started using the lab, and is also used for student accommodation. The unique MyBox house on campus, which is made up of six shipping containers stacked on top of each other, is mainly powered by renewable energy from the sun and wind, with batteries that store electricity.

The project focus on research on the interaction between different energy resources and how to optimize the use of renewable energy. In addition to catering for the pilot-projects which seek extra funding from different local sources, the project arranges seminars and workshops to promote the network and research on renewable energy. Examples of collaboration projects that has been organized are hackathons, study courses for industry and collaborative master theses with industry.

The project started up in 2018 and is still running. There is a large group of researchers involved at UiS, and the activity has been run by Siri M. Kalvig, Helleik L. Syse and Anders Riel Müller. From

IMBM, Siri M. Kalvig (ass. Prof), Knut Erik Teigen Giljarhus (ass. Prof) and PhD-candidates Trond-Ola Hågbo and Usman Shaukat has contributed to the research.

3. References to the research (indicative maximum of six references)

Hågbo, Trond-Ola; Giljarhus, Knut Erik Teigen.
Sensitivity of Urban Morphology and the Number of CFD Simulated Wind Directions on Pedestrian Wind Comfort and Safety Assessments, Preprint
https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4578112

Venkatraman, Kartik; Hågbo, Trond-Ola; Buckingham, Sophia; Giljarhus, Knut Erik Teigen:
Effect of different source terms and inflow direction in atmospheric boundary modeling over the complex terrain site of Perdigão. Wind Energy Science 2023

Hågbo, Trond-Ola; Giljarhus, Knut Erik Teigen.
Pedestrian Wind Comfort Assessment Using Computational Fluid Dynamics Simulations With Varying Number of Wind Directions. Frontiers in Built Environment 2022

Hågbo, Trond-Ola; Giljarhus, Knut Erik Teigen.
Influence of number of simulated wind directions on pedestrian wind comfort maps. COTech (Computational Methods & Ocean Technology)
(3rd); 2021-11-25 - 2021-11-26

Hågbo, Trond-Ola; Giljarhus, Knut Erik Teigen; Hjertager, Bjørn H.
Influence of geometry acquisition method on pedestrian wind simulations. Journal of Wind Engineering and Industrial Aerodynamics 2021 ;Volume 215.

Hågbo, Trond-Ola; Giljarhus, Knut Erik Teigen; Qu, Sen; Hjertager, Bjørn H.
The performance of structured and unstructured grids on wind simulations around a high-rise building. IOP Conference Series: Materials Science
and Engineering 2019

4. Details of the impact *(indicative maximum 750 words)*

FEH has made impact through research projects and dissemination to the society. Besides being a hub for networking and connect industry, authorities and academia, FEH has supported the formation and start-up of several pilot-projects which solves practical problems related to renewable energy and energy-systems. Many of these projects have also secured external funding. Examples of these pilot-projects are "Can solar energy be profitable in Forus, Norway?", "Storing low temperature thermal energy in PCM (Phace Change Material)", "Concept for an energy-neutral Tripod House" and "Waste Heat Energy Integration, Storage and Utilization".

We are currently in the process of creating a positive energy district in Stavanger. This involves the local energy supplier Lyse, together with local industries such as Skretting, the world's largest feed supplier for the aquaculture industry. By analysing the energy supply and demand, and creating spaces for communication between the stakeholders, we will create a significantly more efficient

The project also led to patenting a solution for wind simulation processes in urban environments, this is currently being commercialized by the company Nablaflow, which was also co-founded by university employees.

FEH has had a strong focus on disseminating research and knowledge to the society and has made several contributions in media, along with producing a podcast where topics within renewable energy and society are discussed: Energisnakk – UiS podkast (nettop.guru).

5. Sources to corroborate the impact (indicative maximum of ten references)

https://www.uis.no/en/about-uis/students-hacked-eight-solutions-for-a-sustainable-future

https://www.uis.no/en/research/wind-turbine-and-solar-cells-on-campus

Future Energy Hub | Universitetet i Stavanger (uis.no)

VRI-project - Solar Forus - Final.pdf (uis.no)

https://archiwind.io/
https://nablaflow.io/en/urban-wind-simulations

https://www.uis.no/en/events/uis-at-nordic-edge-2022-how-do-we-create-positive-energy-districts-for-the-future

[University of Stavanger, IMF] [case number 1]

Institution: University of Stavanger
Administrative unit: Department of Mathematics and Physics (TN-IMF)
Title of case study: Safer Births
Period when the underpinning research was undertaken: 2009-2024
Period when staff involved in the underpinning research were employed by the submitting institution: 2009-2024
Period when the impact occurred: 2013-2024

1. Summary of the impact (indicative maximum 100 words)

Safer Births (https://saferbirths.com/) is claimed to be the largest project on saving perinatal lives worldwide. A main outcome of the project is reduced newborn and maternal mortality during birth in low-resource settings. It is estimated that the project has led to two extra lives saved per midwife per year over the project period in hospitals in Tanzania.

In addition, the project has led to increased knowledge on fetal heart rate, transition of newborns at birth and newborn resuscitation that will improve international guidelines. Furthermore, during the project life-saving medical devices and training programs for low-resource setting have been developed.

2. Underpinning research (indicative maximum 500 words)

Safer Births is a large collaborative interdisciplinary research and development project. Some key partners in the project are Haydom and Muhimbili hospitals in Tanzania, Laerdal Global Health, Safer, Stavanger University Hospital, University of Stavanger and Laerdal Medical. Up to 2019 the project involved around 100 persons, including researchers, research staff and engineers, from 12 international institutions. More than 10 PhD students graduated from the original project up to 2019, and more than another 10 from follow up projects afterwards. See more details here: https://saferbirths.com/wp-content/uploads/sites/2/2023/01/Safer-Births-Report-Update-v3_7mb.pdf.pdf

The project has been research based all the way, scientific documentation via peer reviewed research has been a cornerstone in the project. Around 100 research papers have been published related to the project.

The project has led to development of medical devices suited for use during births in low resource settings, and programs and devices for training midwifes and other health care workers. Collecting detailed data and their analysis has been a key part throughout the project to improve and to document the effect of the devices and training programs. For instance, detailed high quality data has been gathered on every birth (around 4-5000 per year) at Haydom hospital over the entire project period (and beyond).

Three members of the statistics group at the department have been involved to analyse the collected data by using and developing suitable statistical methods, at different stages of the project, and thus, have been a crucial part in the projectWe have for instance been involved in calculating the estimated number of lives saved in the project, identifying factors of importance for survival, documenting improved practice and gaining novel understanding of development of newborn heartrate.. Some of our master students have also been working on analysing data from the project

3. References to the research (indicative maximum of six references)

1. Mduma E, Ersdal H, Svensen E, Kidanto H, **Auestad B,** Perlman J. Frequent brief on-site simulation training and reduction in 24-h neonatal mortality--an educational intervention study. *Resuscitation*. 93, 1-7, 2015. doi: 10.1016/j.resuscitation.2015.04.019.
   Documenting improved practice and improved survival due to frequent training in an early phase of the Safer Birth project.

2. Mduma E, **Kvaløy JT**, Søreide E, Svensen E, Mdoe PF, Perlman J, **Johnson CA**, Hussein K, Ersdal HL, Frequent refresher training on newborn resuscitation and potential impact on perinatal outcome over time in a rural Tanzanian hospital: An observational study. *BMJ Open*, 9, 1-10, 2019. doi: 10.1136/bmjopen-2019-030572
   Using statistical process control methods to document that a resuscitation training program leads to improved perinatal survival, with an estimated 250 lives saved over a six-year period in one single hospital. Initial analyses done in the master thesis by Caroline Johnson, master student at IMF.

3. Linde JE, **Schulz J**, Perlman JM, Øymar K, Francis F, Eilevstjønn J, Ersdal HL. Normal Newborn Heart Rate in the First Five Minutes of Life Assessed by Dry-Electrode Electrocardiography. *Neonatology*. 110, 231-7. 2016. doi: 10.1159/000445930.
   Estimation of break points for heart rate changes of healthy newborns in the first minutes of lives using a newborn resuscitation monitor invented as part of the Safer Birth project.

4. Moshiro RD, Perlman JM, Mdoe PF, Hussein K, **Kvaløy JT**, Ersdal HL, Potential causes of early death among admitted newborns in a rural Tanzanian hospital. *PLOS ONE*, 14, 2019. doi: 10.1371/journal.pone.0222935.
   Analysing causes of newborn mortality, for improving future training and treatment.

5. Linde JE**, Schulz J**, Perlman JM, Øymar K, Blacy L, Kidanto H, Ersdal HL. The relation between given volume and heart rate during newborn resuscitation. *Resuscitation*. 117, 80-86. 2017. doi: 10.1016/j.resuscitation.2017.06.007.
   Studying the relationship between tidal volume during initial positive pressure ventilation and heart rate response in resuscitation of newborns, using a generalized additive model.

6. **Schulz J**, **Kvaløy JT**, Engan K, Eftestøl T, Jatosh S, Hussein K, Ersdal H, State transition modeling of complex monitored health data. *Journal of Applied Statistics*. 47, 1915-1935, 2020. doi: 10.1080/02664763.2019.1698523
   Methodological paper on how to analyse complex monitored data, illustrated with data on newborn resuscitation from the Safer Birth project.

7. Ersdal HL, Mdoe PF, Mduma E, Moshiro RD, Guga G, **Kvaløy JT**, Bundala F, Marwa B, Kamala B. "Safer Births Bundle of Care" Implementation and Perinatal Impact at 30 Hospitals in Tanzania—Halfway Evaluation. *Children,* 10, 2023. doi: 10.3390/children10020255.
   Reporting promising results for newborn and maternal mortality in a follow up project implemented at 30 new hospitals, where a bundle of training programs and devices develop during the Safer Births project is used.

4. Details of the impact (indicative maximum 750 words)

It is estimated that at the four hospitals in Tanzania where the Safer Birth project was first implemented around 2 extra lives were saved per midwife per year during 2013-2019. At Haydom hospital (were good baseline data existed) it is estimated that 250 newborns were saved during six years.

This was achieved by a combination of introducing training programs and medical devices suitable for the low-resource setting. More specifically the devices are a digital fetal heart rate monitor to monitor the baby during birth, a heart rate meter to measure the heart rate of newborn babies and an upright bag mask for ventilation of babies not breathing (see more details e.g. here: e or https://laerdalglobalhealth.com/partnerships-and-programs/safer-births-research-project/). In addition, training programs and training devices for training midwives have been developed and continuously improved (see more details e.g. here: https://saferbirths.com/wp-content/uploads/sites/2/2023/01/Safer-Births-Report-Update-v3_7mb.pdf.pdf). Although developed for the low resource setting, some of these devices have also turned out to be useful for use in developing countries, e.g. the heart rate meter is now used for research projects at Norwegian hospitals.

Furthermore, the research done as part of the project has led to increased knowledge on fetal heart rate, transition of newborns at birth and newborn resuscitation. Insight from this research will contribute to improve international guidelines.

The research output is documented in the around 100 published research papers, more than 10 completed PhD theses and more than 10 ongoing PhD projects in continuations of the project. Very important here is that a majority of these PhD students are Tanzanians, and the project has thus led to important capacity building also on the research side in Tanzania. Some of the first Tanzanians graduating with PhDs from the project are now leading persons in the Safer Births Bundle of care project described below, and other related projects.

A continuation of the Safer Birth project, called the Safer Births Bundle of care started in 2021. In this project the key elements developed during the Safer Birth project is implemented at 30 hospitals in rural parts of Tanzania (see more detail here: https://laerdalglobalhealth.com/cdn-498d65/globalassets/lgh/partnerships--programs/safer-births/sbbc-mini-report-2023.pdf). This project is funded by winning a call from the Global Financing Facility (GFF). Among 320 proposals the Safer Births Bundle of Care was rated to have the highest impact potential of all. Even further financing from GFF to scale the project up to over one hundred hospitals was received last year, and the scale up is being rolled out in the start of 2024. The statistics group are part also of this project, with an allocated part of the budget.

There is also an offspring from the original Safer Births project in form of a Safer Births project for high resource settings, led from Stavanger University hospital and with many collaborating partners: **https://www.helse-stavanger.no/fag-og-forskning/forskning-i-helse-stavanger/forskningsgrupper/safer-births**

5. Sources to corroborate the impact (indicative maximum of ten references)

The project has received a lot of attention in media, at conferences among politicians and health officials at all levels in Tanzania, Norway and other countries. Some of these stories are documented here: https://saferbirths.com/news/

See also:

https://saferbirths.com/testimonials/
https://saferbirths.com/save-stories/

[University of Stavanger, IMF] [case number 2]

Institution: University of Stavanger (UiS)
Administrative unit: Department of Mathematics and Physics (IMF)
Title of case study: Skolebesøk / School visits
Period when the underpinning research was undertaken: Since 2012 and onwards
Period when staff involved in the underpinning research were employed by the submitting institution: From 2012 and onwards
Period when the impact occurred: 2019-onwards

1. Summary of the impact (indicative maximum 100 words)
This section should briefly state what specific impact is being described in the case study.

The institute runs a very successful project "Skolebesøk" that enables institute researchers to visit upper secondary schools all over Norway and present the main findings and background for their research. This project disseminates research results into the wider community, inspires the next generation of researchers and supports schoolteachers in their vital societal role. The project was begun in 2019 but has since been extended and is still ongoing due to its success and the clear societal needs it addresses.

2. Underpinning research

- Reference 1 discusses possible materials for hydrogen storage and in general energy storage. Green transition and energy have been topics nationally in the past decade. Presenting this research work in schools shows what solutions are being developed and integrates with classroom discussions about the challenges and potential of various renewable energy sources.
-
  References 2 and 4 deal with both the standard model of particle physics and cosmology. This research addresses fundamental questions about how the standard model of particle physics can be extended and what impact this may have for the evolution of the universe and its overall structure. These topics are very popular with students and teachers alike.

  References 3 and 6 below relate to medical statistics. Presenting these in schools demonstrates how we use mathematics and statistics to assess safety and mitigate diseases. Covid was a very big topic in the media and the daily lives of students in 2021-2022 and so these topics provide an excellent jumping off point for discussing statistics and how we quantify uncertainties in epidemiology.
-
  Presenting reference 5 in schools provides students with an insight into the new astronomical field of gravitational waves. It shows how relatively simple statistical tools can be used to identify gravitational wave signals that are many times quieter than the ambient noise level. This work is also particularly suited to presentation in schools since it addresses some claims in the media that gravitational waves had not in fact been detected convincingly and allows a broader discussion with the students about the role of the media in portraying scientific research results.

3. References to the research (indicative maximum of six references)

An indicative selection of research relevant to the project is listed here.

1) Recent progress in magnesium borohydride Mg(BH4)(2): Fundamentals and applications for energy storage.
Zavorotynska, O.; El-Kharbachi, A.; Deledda, S.; Hauback, B. C.,
International Journal of Hydrogen Energy 2016, 41 (32), 14387-14403. August 2016, DOI: 10.1016/j.ijhydene.2016.02.015

2) Dimensional reduction of the Standard Model coupled to a new singlet scalar field
Tomáš Brauner, Tuomas V. I. Tenkanen, **Anders Tranberg**, Aleksi Vuorinen, **David J. Weir**
Journal of High Energy Physics 03 (2017) 007, March, 2017
DOI: 10.1007/JHEP03(2017)007

3) Thyroidectomy Versus Medical Management for Euthyroid Patients with Hashimoto Disease and Persisting Symptoms. A Randomized Trial
Ivar Guldvog, MD, PhD, Laurens Cornelus Reitsma, MD*, Lene Johnsen, MD*, Andromeda Lauzike, MD, Charlotte Gibbs, MD, Eivind Carlsen, MD, Tone Hoel Lende, MD, Jon Kristian Narvestad, MD, Roald Omdal, MD, PhD, **Jan Terje Kvaløy**, PhD, Geir Hoff, MD, PhD, Tomm Bernklev, PhD†, and Håvard Søiland, MD, PhD
Annals of Internal Medicine 170(7):453-464, March 2019. DOI: 10.7326/M18-0284.

4) A study of inhomogeneous massless scalar gauge fields in cosmology
Ben David Normann, Sigbjørn Hervik, Angelo Ricciardone, Mikjel Thorsrud
Contribution to: MG15, 1378-1383, September 2019
DOI: 10.1142/9789811258251_0199

5) Pearson cross-correlation in the first four black hole binary mergers
Paolo Marcoccia, Felicia Fredriksson, **Alex B. Nielsen** and **Germano Nardini**
Journal of Cosmology and Astroparticle Physics 11 (2020) 043, August 2020. DOI 10.1088/1475-7516/2020/11/043

6) A Risk Model of Admitting Patients with Silent SARS-CoV-2 Infection to Surgery and Development of Severe Postoperative Outcomes and Death. Projections Over 24 Months for 5 Geographical Regions
Soreide, Kjetil MD, PhD, FRCS, FACS∗,†; Yaqub, Sheraz MD, PhD, FEBS‡; Hallet, Julie MD, MSc§,¶; **Kvaløy, Jan Terje** PhD‖,∗∗; **Kleppe, Tore Selland** PhD
Annals of Surgery 273(2):208-216, February 2021. DOI: 10.1097/SLA.0000000000004583

4. Details of the impact (indicative maximum 750 words)

When the project was started, we were delighted by the response from schools, which indicated a very real need for researchers and cutting-edge research in schools. Because of Covid and other constraints, visits have been performed both physically and digitally. The students are given the opportunity to interact directly with researchers, ask questions and are challenged to think critically about the questions raised by the research.

While not all of the research produced by the institute (administrative unit) is suitable for presentation in schools, there are many research results that are. These are often connected to wider societal challenges, such as medical statistics and pandemics, climate change and energy transition and the search for origins in cosmology and fundamental physics. An initial list of potential presentation topics was prepared by the institute and sent to schools across the country. Schools could then choose which topics would fit best with their needs and interests and researchers could be matched with schools as necessary. Presentation materials and presentation ideas were shared across the institute and almost all members of the institute have had the opportunity to participate.

A main driver of the project is to bring research results to the classroom along with appropriate background to understand their relevance. This provides essential motivation and context for the students' learning at schools. It directly connects their classroom experience to the research frontier and aims to inspire their future career choices. It is important for actual research to be presented in the schools. It is a great benefit for the students to see and meet researchers in real life, as opposed to the often one-sided caricatures presented in the media. Students are presented what it actually means to do research through the peer-review and journal process. While not all students aspire to be researchers in their future careers, the ones that do are often isolated and disconnected. Meeting researchers from the university can often be essential in encouraging them to persevere with their ambitions.

The project additionally provides welcome support for the teachers and bridges the gap between the university and schools. With the emphasis on broad, inquiry-based learning in the Norwegian school curriculum, teachers can often combine the researcher visits directly into ongoing lesson plans in STEM subjects. Most of the research presented in the schools is directly relevant to elements in the school curriculum, or as applied case studies to show the application of elements of the school curriculum.

The short-term impact of the project is assessed by written and verbal feedback from students and teachers. This feedback has been very positive, as evidenced by many repeat invitations. The longer-term impact, of inspiring the next generation of researchers, is harder to quantify and cannot be assessed at the present time. This impact is however no less important than the short-term impact.

Since the project started in 2019, we have visited the following upper secondary schools in Norway. This is an ongoing project and we have now visited multiple schools, multiple times and hope to extend this even further**.**

Ølen vgs
Sortland vgs
Kvitsund Gymnas, in Telemark
Arendal vgs
Bamble vgs
Gjennestad vgs
Rjukan vgs
Drottningborg vgs
Sandnes vgs
St. Svithun vgs, Stavanger
Hetland vgs, Stavanger

Sola vgs
Skeisvang vgs
Strand vgs
Dalane vgs
Spjelkavik vgs
Molde vgs
Sykkulven vgs
Volda vgs
Rauma vgs, Åndalsnes
Edvard Munch vgs., Oslo
Fyrstikkalleen skole, Oslo
Meløy vgs, Nordland

5. Sources to corroborate the impact (indicative maximum of ten references)

Bente Espedal, head of science, Sandnes vgs., bente.espedal@skole.rogfk.no, 95 44 41 48

Joao Loureiro, head of science and sport, Stord vgs., jll@vlfk.no, 93 03 15 66

Margrethe Steine Solevåg, teacher, Molde vgs, margrethe.steine.solevag@mrfylke.no, 98 66 56 22

[UiT The Arctic University of Norway, Department of technology and safety] [case number]

Institution: UiT The Arctic University of Norway
Administrative unit: Department of Technology and Safety
Title of case study: Building autonomous sea-spray collector and flux measurement equipment for spray icing modelling and icing-risk decision support in the Norwegian maritime sector
Period when the underpinning research was undertaken: 2021-2024
Period when staff involved in the underpinning research were employed by the submitting institution: 2021-2024
Period when the impact occurred: 2022-2024

1. Summary of the impact (indicative maximum 100 words)

Sea-spray ice models predict icing phenomena and its severity in Arctic waters, a case in point is MINCOG model used by MET-Norway over the Barents Sea. The main scientific impact of this case study is generating knowledge beyond the state-of-the-art through designing, developing and deploying autonomous devices that can conduct real-time spray-flux field measurements. AI-based models are being developed to develop spray flux models that can be employed in icing estimation models to significantly improve the accuracy of icing models. The key societal impact is to help seafarers and maritime stakeholders have more accurate information about icing on their structures to make solid risk-informed decision when designing their operations (e.g., fishing, fish farming, search-and-rescue, offshore industry).

2. Underpinning research (indicative maximum 500 words)

Ice accretion on marine structures and ships significantly impacts crew safety and sea-keeping performance and may lead to capsizing, as seen in the recent tragic incidents of fishing vessels ONEGA, 2020, and Scandies Rose, 2019.

State-of-the-art models for icing estimation (e.g., MET-Norway's employed MINCOG) have been developed to provide warnings using the estimated icing rates. A key element and the primary source of uncertainty in such models is the sea-spray flux. The underpinning of the research for the claimed impact is revolved around spray flux modelling using field measurement, as the identified research gap. Development of robust spray flux models relies on conducting spray flux measurements, which is faced with a range of logistical, technological, cost, and safety obstacles. Due to the lack of standardised equipment or methods for spray measurements and concerns regarding the generalisability and transferability of resulting empirical expressions, different researchers have resorted to employing their own tailored measurement equipment.

In this case study, the novel SPRICE sea-spray collector device and SPRICE frequency-and-duration measurement devices are designed (using CFD simulations), developed, tested in laboratory, and deployed in the field on a fish cage in Northern Norway. They can accurately work even in adverse and harsh weather situations without needing frequent human assistance, enabling long-term measurements, on both fixed and moving structures. The proposed devices can be mounted on vessels, fish cages, and other type of offshore structures. They have a low cost of design, development, operation and maintenance, and are able to collect real-time data autonomously and transfer the data to MET-Norway's open access repository, to be used alongside other meteorological and oceanographic data for developing spray flux models for icing estimations.

Currently, a methodological framework for data analysis is being developed. To this aim, ML algorithms are used to prepare and filter the collected measurements. Advanced ML and Deep-

learning algorithms are being employed to develop relationships for the duration and frequency of spray as a function of explanatory meteorological and oceanographic parameters.

Therefore, the end-to-end product includes detailed documentation of how to design, develop, and build the SPRICE devises suitable for mounting on different marine structures, and proposing an AI-base modelling framework to develop spray flux models to be further integrated in icing estimation models.

The underpinning research started with funding from Framsenteret during 2019-2021 and was taken further being funded by NFR under the call "Collaborative Project to Meet Societal and Industry-related Challenges; 2021-2025" with partners from fish farming and fishing industries, MET and SINTEF, Norwegian Coastal Administration.

Names of key researchers:
Associate Prof. Masoud Naseri (UiT, 2019 – now); Associate Prof. Kåre Edvardsen (UiT, 2021 – now); PhD candidate Sushmit Dhar (UiT, 2021 – now); Eirik Samuelsen (MET, 2019 – Now), Hassan Khawaja (UiT, 2021 – now), Prof. Javad Barabady (UiT, 2020 – now); Associate Prof. Karl Gunnar Aarsæther (SINTEF, 2019 – 2020 & UiT, 2021). Pål Konrad Vevang (Engineer, UiT), Kristian G. Andersen (Engineer, UiT), Ståle Antonsen (Engineer, UiT), Olaf Weisser (Engineer, MET), Bikas Chandra Bhattarai (Engineer, MET), Vegar Kristiansen (Engineer, MET), Børge Hansen (Engineer, MET)

3. References to the research (indicative maximum of six references)

1. S. Dhar, M. Naseri, T. Zhu, and K. Edvardsen. 2024, "A Novel Device for Accurate Measurement of Spray Frequency and Duration using Capacitive Liquid Sensors in Marine Icing Estimation," *Submitted* for ISOPE, Rhodes, Greece, June 16−21 2024.
2. Dhar, S., Naseri, M., Khawaja, H.A., Edvardsen, K., Zhu, T., 2023a. Design, development and deployment of a novel sea spray collector for sea-spray flux measurements. Cold Regions Science and Technology 218, 104096. https://hdl.handle.net/10037/32500
3. Dhar, S., Naseri, M., Khawaja, H.A., Samuelsen, E.M., Edvardsen, K., Barabady, J., 2023b. Sea-spray measurement tools and technique employed in marine icing field expeditions: A critical literature review and assessment using CFD simulations. Cold Regions Science and Technology 217. https://hdl.handle.net/10037/32297
4. Dhar, S, Samuelsen, EM, Naseri, M, Aarsæther, KG, & Edvardsen, K. "Spray Icing on ONEGA Vessel- A Comparison of Liquid Water Content Expressions." Proceedings of the ASME 2022 41st International Conference on Ocean, Offshore and Arctic Engineering. Volume 5A: Ocean Engineering. Hamburg, Germany. June 5–10, 2022. V05AT06A033. ASME. https://hdl.handle.net/10037/27465
5. Naseri, M. and Samuelsen, E. M. (2019) 'Unprecedented Vessel-Icing Climatology Based on Spray-Icing Modelling and Reanalysis Data: A Risk-Based Decision-Making Input for Arctic Offshore Industries', Atmosphere, 10(4), pp. 197. https://www.mdpi.com/2073-4433/10/4/197
6. Shojaei Barjouei, A., Naseri, M., 2021. A Comparative Study of Statistical Techniques for Prediction of Meteorological and Oceanographic Conditions: An Application in Sea Spray Icing, Journal of Marine Science and Engineering, 9(5), 539, https://www.mdpi.com/2077-1312/9/5/539#

4. Details of the impact (indicative maximum 750 words)

4. Details of the impact (indicative maximum 750 words)

Short-term and long-term scientific impacts:

The current state-of-the-art lacks a generalisable framework for estimating the spray flux, frequency and duration. Our proposed frameworks and the developed devices tackle this issue and provide a solution that can be applied in different sectors including fishing, fish farming, oil and gas, search and rescue, and coast guard. The scientific community can benefit from the results of our project through

- designing, developing and implementing the proposed devices for their own application of interest,
- collecting real-time spray flux data autonomously even under harsh operating conditions,
- preparing and analysing the data using suggested ML- and AI-based solutions and training their own model applied to their specific application area,
- predicting the parameters of interest in spray flux, and
- integrating the results into their icing estimation models for more accurate predictions

Over time, different open-access databases can be generated and by implementing AI-based transfer-learning approaches, more comprehensive and generalisable spray flux relationships can be developed, particularly, where conducting field campaigns for spray flux data collection is not feasible. Also, our produced results pave the way towards developing icing estimation models applicable to fish cages (at the moment, there is no icing estimation models applicable to fish farms).

Short-term and long-term societal impacts:

Currently, we are using the knowledge generated in another product (IceBox) that is being built. It can be placed on fish cages to provide a warning on the severity of upcoming probable icing situations, and thus help improve the safety of fish farming industry and reduce the attributed environmental risks.

In the long-term, our proposed solutions can be employed in navigation for fishing, search and rescue vessels, coast guard vessels. The generated databases can be used to develop more accurate flux models to be integrated in icing estimation models, in particular in operationalised MET-Norway's MINCOG model, to provide icing warning over the Barents Sea. This contributes to reliable warnings and thus to safer navigation and more efficient risk-informed route planning for vessels in Arctic waters.

Also, the results of the project can help build robust and accurate icing estimation models for fish cages. The results of such models can help the stakeholders to safely and efficiently manage their operation and the icing risks.

Dissemination:

Talks and presentations at national / international workshops and symposiums:

1. Arctic Safety Conference, UNIS, Longyearbyen, 2021
2. SeaNorth Tech Cluster (a network consisting of aquaculture actors both on the production side and on the supplier side), Narvik, 2021
3. SPRICE Workshop, Tromsø, 2021
4. Cold Climate Technology & Icing Seminar, Narvik, 2022
5. Microspray workshop, NTNU, Trondheim, 2022
6. International Conference of Multiphysics, Oslo, 2022
7. Arctic science summit week, Vienna, 2023

8. DNV Nordic Maritime Universities Workshop, Aalto University in Espoo, Finland, 25-26 January 2024

Particularly, we proposed and chaired a session in Arctic Science Summit Week, where the international researcher well perceived our work. Please see: (SPRICE at ASSW 2023 Science Symposium | UiT)

Peer-reviewed proceedings of international conferences:

- The 41st International Conference on Ocean, Offshore & Arctic Engineering, Hamburg (OMAE), June 2022 (Nivå 1)
- The 18th International Society of Offshore and Polar Engineers Conference (ISOPE), June 2024, Greece (Nivå 1).

International peer-reviewed journal articles:

- Two peer-reviewed scientific articles published in a level 2 journal (Nivå 2)

The exploitation is yet to be realized given the timeline of the published case study results. The exploitation of the results in MET-Norway's icing prediction frameworks is relatively certain in close future, as MET is a formal partner of the project and keen to implement the research results in their operationalized icing warning system for the Barents Sea.

Administrative unit's role: The Department of Technology and Safety is the key role player in the research. It owns and leads the project, and the majority of the work was conducted by the enrolled PhD candidate and the UiT's researchers involved.

Beneficiaries: Fish farming companies; fishing industry (fishing vessels), research and rescue (vessels), coast-guard (vessel), costal administration (vessels for search and rescue and managing the potential oil spills) – In particular local industries and communities in Northern Norway and those involved with maritime operations in the Barents Sea, and in general, stakeholders involved in the above-mentioned application areas both nationally and internationally in cold-climate regions and Arctic waters. Gratanaglaks AS (fish farming company in Northern Norway) provided the opportunities for field studies and equipment deployment.

5. Sources to corroborate the impact (indicative maximum of ten references)

[UiT The Arctic University of Norway, Department of technology and safety] [case number]

Institution: UiT The Arctic University of Norway
Administrative unit: Department of Technology and Safety
Title of case study: SeaTech Horizon2020 Project - Next Generation Short-sea Ship Dual-Fuel Engine and Propulsion Retrofit Technology
Period when the underpinning research was undertaken: 2020-2023
Period when staff involved in the underpinning research were employed by the submitting institution: 2020-2023
Period when the impact occurred: 2021-2023

1. Summary of the impact (indicative maximum 100 words)

The SeaTech consortium (SeaTech2020.eu) is proposing to develop two symbiotic ship engine and propulsion innovations, which when combined, lead to an increase of 30% in fuel efficiency and emission reductions of 99% for NOx, 99% for SOx, 46% for CO_2 and 94% for particulate matter. The innovations are characterized by high retrofitability, maintainability and offer ship owners a return on investment of 400% due to fuel and operational cost savings. Assuming only 10% of EU short-sea vessels would be retrofitted with SeaTech, this would result in CO_2 savings of 32.5 million tons annually.

2. Underpinning research (indicative maximum 500 words)

As mentioned before, this is proposing to develop two symbiotic ship engine and propulsion innovations, which when combined, lead to an increase of 30% in fuel efficiency and radical emission reductions of 99% for NOx, 99% for SOx, 46% for CO_2 and 94% for particulate matter. The innovations will be characterized by high retrofitability, and maintainability and offer ship owners a return on investment of 400% due to fuel and operational cost savings. The proposed renewable-energy-based propulsion innovation is the bio-mimetic dynamic wing mounted at the ship bow to augment ship propulsion in moderate and higher sea states, capturing wave energy, producing extra thrust and damping ship motions. The proposed power generation innovation is based on the idea of achieving ultra-high energy conversion efficiency by precisely controlling the engine to achieve radically reduced emissions. The ultimate objective of the project is to scale up both technologies, demonstrate them in relevant environments, and finally model the expected complementarities and synergy effects of deploying both innovations on a short-sea vessel scenario by extrapolating demonstration data with the help of bespoke Advanced Data Analytics Framework (ADAF).

The UiT contribution (that was conducted during the project period from 2020 to 2023) is the development of the ADAF by considering the large-scale data sets collected from both innovations, i.e. the SeaTech engine is developed and tested under the Wartsila Engine Laboratory and the Dynamic Wing was tested in a large scale vessel. The data sets are combined into a data science environment, where the respective machine learning (ML) and artificial intelligence (AI) are used to combine both engine and propulsion innovations to quantify the ship performance improvements due to the SeaTech innovations. In addition, the respective life cycle cost analysis (LCCA) and environmental impact to support the retrofitting of such technologies, i.e. SeaTech engine and Dynamic Wing, on existing short-sea vessels have also been studied by the UiT researchers. The respective project KPIs, e.g. an increase of 30% in fuel efficiency and radical emission reductions of 99% for NOx, 99% for SOx, 46% for CO_2 and 94% for particulate matter, and return on investment of 400% due to fuel and operational cost savings, have been verified under the ADAF and that has been published.

As the overall impact of the project, the project partners envisage to commercialization of both symbiotic innovations in the European and Asian short-sea markets by 2025, followed by the adjacent deep-sea market. Assuming only 10% of EU short-sea vessels would be retrofitted with SeaTech, this would result in CO_2 savings of 32.5 million tons annually, which equals the emissions of 200,000 passenger cars/year. Further impact includes savings of EUR 85.2 billion in health and climate change damages due to lower emissions, the creation of +100 jobs at the project partners with a cumulative net profit of EUR 820 million in the first 5 years post-commercialization, and the indirect creation of 250 new jobs in the EU shipyard industry.

The name of the Key Researchers: Lokukaluge Prasad Perera (WP Leader-Professor, UiT, 2020-2023), Bjørn-Morten Batalden (Associate Professor, UiT, 2020-2023), Jan Emblemsvåg (Associate Professor II, UiT, 2020-2022), Magne-Petter Sollid (Lecturer, UiT, 2020-2023), Khanh Quang Bui (PhD Position, UiT, 2020-2023), Hadi Taghavifar (PostDoc Position, UiT, 2021-2023), Mahmood Taghavi (PhD Position, UiT, 2021-2023),

The project has received funding from the European Union's Horizon 2020 research and innovation program under the grant agreement No 857840.
The SeaTech project

3. References to the research (indicative maximum of six references)

- K.Q. Bui and L.P. Perera "Advanced data analytics for ship performance monitoring under localized operational conditions," Journal of Ocean Engineering, vol. 235, 2021. (DOI: https://doi.org/10.1016/j.oceaneng.2021.109392)
- K.Q. Bui, L.P. Perera and J. Emblemsvag "Life-cycle cost analysis of an innovative marine dual-fuel engine under uncertainties," Journal of Cleaner Production, vol. 380, part. 2, 2022, 134847. (DOI: https://doi.org/10.1016/j.jclepro.2022.134847)
- H. Taghavifar and L.P. Perera "Data-driven modeling of energy- exergy in marine engines by supervised ANNs based on fuel type and injection angle classification ," Journal of Process Safety and Environmental Protection, 2023. (DOI: https://doi.org/10.1016/j.psep.2023.02.034)
- H. Taghavifar and L.P. Perera "Life cycle emission and cost assessment for LNG-retrofitted vessels: the risk and sensitivity analyses under fuel property and load variations," Journal of Ocean Engineering, Vol. 282, 2023. (DOI: https://doi.org/10.1016/j.oceaneng.2023.114940)
- M. Taghavi and L.P. Perera, "Advanced Data Cluster Analyses in Digital Twin Development for Marine Engines towards Ship Performance Quantification," Journal of Ocean Engineering, 2023. (DOI: https://doi.org/10.1016/j.oceaneng.2024.117098)
- M. Taghavi and L.P. Perera, "Multiple Model Adaptive Estimation Coupled with Nonlinear Function Approximation and Gaussian Mixture Models for predicting Fuel Consumption in Marine Engines," In Proceedings of the 42nd International Conference on Ocean, Offshore and Arctic Engineering (OMAE 2023), Melbourne, Australia, June, 2023 (OMAE2023-103249).

4. Details of the impact (indicative maximum 750 words)

The respective KPIs on the shipping industry, as discussed before, are satisfied under this project and that are presented in various publications. If the KPIs of the SeaTech project can be summarized as:

- **Increase of 30% in fuel efficiency –** The project conclusions and activites can be summarised as: **(1)** The life cycle assessment (LCA) section is conducted to compare typical diesel and LNG fuels with selected short and deep-sea ship routes, **(2)** the life cycle cost assessment (LCCA) indicated that the fuel quality is more influential than the load variations in ship navigation, **(3)** The results also showed that the feasibility of using good

quality LNG instead of poor diesel characteristics in a selected ship is guaranteed within 30% of the price sensitivity range and 10% risk level by Monte Carlo simulation on the proposed LNG fuel case.

- **Emission reductions of 99% for NOx, 99% for SOx, 46% for CO_2 and 94% for particulate matter -** The project conclusion can be summarised as: **(1)** A 39% GHG emission reduction and up to a 22% fuel efficiency can be achieved under more optimal operational conditions by replacing LNG with diesel, **(2)** 85% operation partial load gives more profitability and feasibility of the project than 50% operation - partial load, **(3)** Diesel impact coefficient is higher than the effect of the LNG pricing in the fuel market, **(4)** The fuel consumption variations under different engine loads (50% max to 85% min) can decrease the payback period from 6-years to 4-years as per the LCCA.
- **Return on investment of 400% due to fuel and operational cost savings -** The project conclusion can be summarised as: **for the SeaTech engine** – **(1)** the dual-fuel SeaTech engine appears to be more cost-effective than the diesel engine since it has lower Net Present Cost (NPC) (€17,409K versus €19,213K), the Net Saving (NS) (€1,804K) greater than zero and the Saving-to-Investment Ratio (SIR) (4.95) greater than 1.0, **(2)** The uncertainty analysis using scenario sensitivity analyses uncovers that fuel prices are highly influential in affecting changes in the NPCs of these engines, i.e. sensitive to the high gas price scenarios, **(3)** In the case of carbon pricing, the carbon prices result in significantly higher NPCs of these engines in the high carbon price scenarios, **(4)** Regardless of fuel prices and carbon pricing scenarios, a 33% reduction in CO2 emissions can be achieved by opting for the dual-fuel engine, **for the Dynamic wing** – **(1)** The wing breakdown structure supports the estimation of Construction, Maintenance & Disposal costs, **(2)** Apart from the operation cost, which is the dominant phase in terms of cost, and from which comes the benefit for the system, construction cost is extremely important, ranging between € 530K and € 911K, **(3)** Preliminary results only for the wing and the expected decrease in fuel consumption, with uncertainty analysis (Monte Carlo simulation), show indicatively an average of € 575K Net Savings (5) Overall average cost for the construction phase € 855K; overall yearly cost for wing operation € 36K; overall yearly cost for onboard maintenance € 8K and for drydock maintenance € 30K; benefits from metal recycling € 107K, and **the combined innovations** – **(1)** The more efficient the system can use the wave according to wave height, wavelength, and vessel speed, the less emission is generated, resulting in greater green to red ratio (GRR) and economic profitability, **(2)** For example, the GHG amount can be reduced from 3218.9 tCO2-eq (corresponding to Hs = 5 m) to 1822.3 tCO2-eq (corresponding to no foil and DF operation), based on annual operations of a selected vessel, **(3)** This amount of emission reduction translates to associated €138,256 more credit, **(4)** The NPV of hybrid technology is higher than DF engine alone, **(5)** The NPV (as the prime economic indicator) of the DF engine alone is always higher in 2023 compared to 2022, **(6)** However, for the hybrid technology, the NPV of 2022 and 2023 are approaching to a same value with Hs increase, **(7)** In addition, for λ/l[1] = 1.0 and λ/l = 1.2, the NPV of the hybrid propulsion system for 2022 is higher than 2023, **(8)** For different vessel speeds at λ/l = 1 and 50% load, the NPVs of 2022 and 2023 are approximately 50% and 30% higher than the no-foil case, respectively **(9)** For the favorable wave condition, the hybrid propulsion system shifts away from the infeasible zone under adverse fuel pricing of diesel and LNG in a way that for λ/l = 1.0 and λ/l = 1.2, the ±30% fuel cost change has no effect on the financial security of the investment, **(10)** The diesel cost, LNG cost, initial cost (CAPEX), and GRR have the highest impact on NPV, accordingly.
- **These results will be published in the paper under review:** H. Taghavifar, K. Q. Bui, L. P. Perera, K. Belibassakis, 'Symbiotic ship propulsion innovation technology from the lifecycle

[1] Wave length – λ & vessel length - l

costing perspective: combined DF gas engine and biomimetic hydrodynamic wing vs. conventional diesel engine ', Vol. xxxx, 2024.

5. Sources to corroborate the impact (indicative maximum of ten references)

The following publications are developed by collaborating with other academic institutes (National Technical and Southampton University) and industrial partners (Wartsila, Norwegian ship-owner Utkilen).

- L.P. Perera, and K. Belibassakis, "Energy-Efficient Marine Engine and Dynamic Wing Evaluation under Laboratory conditions to achieve Emission Reduction Targets in Shipping," In Proceedings of the 42nd International Conference on Ocean, Offshore and Arctic Engineering (OMAE 2023), Melbourne, Australia, June, 2023 (OMAE2023-103192).
- L.P. Perera, K. Belibassakis, E. Filippas and M. Premasiri "Hybrid Engine-Propeller Combinator Diagram as the basis for Advanced Data Analytics," In Proceedings of the 41st International Conference on Ocean, Offshore and Arctic Engineering (OMAE 2022), Hamburg, Germany, July, 2022 (OMAE2022-79583).
- N. P. Ventikos, L. P. Perera, P. Sotiralis, E. Annetis, E. V. Stamatopoulou, "A Life-Cycle Cost Framework for Onboard Emission Reduction Technologies: The Case of the Flapping-Foil Thruster Propulsion Innovation," In Proceedings of the 41st International Conference on Ocean, Offshore and Arctic Engineering (OMAE 2022), Hamburg, Germany, July, 2022 (OMAE2022-79031).
- L.P. Perera, N.P. Ventikos, S. Rolfsen, and A. Oster "Advanced Data Analytics towards Emission Reduction Retrofit Technology Integration in Shipping," In Proceedings of the 31st International Ocean and Polar Engineering Conference 5th International Conference (ISOPE 2021), Rhodes, Greece, June, 2021 (ISOPE-I-21-4184).

[UiT_DeptIndustrialEngineering] [1]

Institution: UIT The Arctic University of Norway
Administrative unit: Department of Industrial Engineering
Title of case study: Intelligent Manufacturing and Manufacturing System Management
Period when the underpinning research was undertaken: 2012-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2012-2022
Period when the impact occurred: whole period and beyond

1. Summary of the impact

Dept. of Industrial Engineering has been working diligently from 2012 to 2022 to advance and share knowledge in Intelligent Manufacturing and Manufacturing System Management (IMMSM). Throughout this period, our cascaded projects have made a significant and enduring impact on regional, national, and European industries, benefiting largely their stakeholders and organizations, economically, socially, and environmentally.
Our impact is evidenced through our engagement, i.e., as part of a European network for agile production (TRINITY). Our influence is also demonstrated by our strong partnerships with both industrial and public sectors, specifically through our association with the technological competence center of Arctic Logistics Operations (ArcLog).

2. Underpinning research

IMMSM is missioned to focus on developing systematic technological solutions for regional industries. The solutions developed are aimed at assisting the regional industries remain competitive and sustain in European and global markets.
Between 2012 and 2022, technological innovation has experienced exponential growth. This growth has reshaped the business landscape and fundamentally changed the way of value generation. This presents industries in outlying regions, such as ours in Northern Norway, with the potential for newfound competitiveness and business opportunities, despite their geographical distance from major economic centers.
IMMSM invested significant effort in investigating these potentials and contributed largely to raise awareness and facilitate understand of these technological and business opportunities among industries and general public. We have also been committed to develop tailored system solutions, especially for small- and medium-sized enterprises (SMEs) which serve as the backbones of Norwegian and European economies. All IMMSM's research efforts are underpinned by following key elements:

1. providing comprehensive and up-to-date depictions of technological development and its impact on the business,
2. fostering awareness and enhancing understanding of technological advancements at industrial practitioners,
3. offering measurement and verification of industrial pathways for sustainable development,
4. providing tailored technological and system solutions to address industrial challenges,
5. building collaborative platforms for facilitating business alliances and industrial-oriented research,
6. providing customized educational solutions to support technological transformation in industries.

Researchers from the department involved in IMMSM:

- Prof. Dr. Wei Deng Solvang (Head of research group IMaLog since 2012, also Department Head of Industrial Engineering 2012-2018; acting Head of Department Dec., 2023-)
- Prof. Dr. Bjørn Solvang (also Dean of faculty of engineering science and technology 2012-2022)
- Prof. Åsa Ericsson (20% in 2018 – 2024)
- Dr. Gabor Sziebig (PhD research fellow 2007-2013, 100% Associate professor 2013 – March 2021, and 20% beyond 2021)
- Dr. Hao Yu (PhD research fellow 2016-2020 Associate professor March 2020 -)
- Dr. Diana Santalova Thordarson (PostDoc Jan. 2021- Dec. 2022)
- Senior researcher Dr. Pourya Pourhejazy (Oct. 2021 -)
- Dr. Xu Sun (PhD research fellow 2018-2022, PostDoc 2023 -)
- Dr. Beibei Shu (PhD research fellow 2016-2022, PostDoc 2023 -)
- Dr. Halldor Arnarson (PhD research fellow 2021 – 2023, researcher 2023 -)
- PhD research fellow Mathias Sæterbø (Aug. 2018 -)
- PhD research fellow Rami Nourddine (June 2020 -)
- PhD research fellow Sujan Maharjan (June 2020 -)
- PhD research fellow Natalia Khan (April 2021 -)

3. References to the research:

1. **Mathias Sæterbø, Wei Deng Solvang**. " A Readiness Model for Facilitating the Implementation of Metal Additive Manufacturing at SMEs". 2023 IEEE Conference on Technologies for Sustainability (SusTech). DOI: 10.1109/SusTech57309.2023.10129602
2. **Wei Deng Solvang**, Akshay Nagarajan, **Diana Santalova Thordarson**. "A General Framework for Measuring and Reporting Sustainability of the Aquaculture Industry". In: Wang, Y., Yu, T., Wang, K. (eds) Advanced Manufacturing and Automation XII. IWAMA 2022. Lecture Notes in Electrical Engineering, vol 994. Springer, Singapore. https://doi.org/10.1007/978-981-19-9338-1_69
3. Johan Lugnet, **Åsa Ecicson,** Andreas Larsson. "Realization of Agile Methods in Established Processes: Challenges and Barriers". MDPI Special Issue New Trends in Design Engineering. 2021. https://doi.org/10.3390/app11052043
4. **Halldor Arnarson,** Hussein Mahdi Yaseen Al-Sallami**, Bjørn Solvang,** Bernt Arild Bremdal. "Towards automatic configuration and programming of a manufacturing cell". Journal of manufacturing systems. https://doi.org/10.1016/j.jmsy.2022.06.005
5. **Hao Yu, Xu Sun, Wei Deng Solvang**, Xu Zhao. "Reverse Logistics Network Design for Effective Management of Medical Waste in Epidemic Outbreaks: insights from the Coronavirus disease 2019 (COVID-19) outbreak in Wuhan (China)". nt. J. Environ. Res. Public Health 2020, 17(5), 1770; https://doi.org/10.3390/ijerph17051770.
6. Tero Kaarlela**, Halldor Arnarson,** Tomi Pitkäaho**, Beibei Shu, Bjørn Solvang,** Sakari Pieskä. "Common Educational Teleoperation Platform for Robotics Utilizing Digital Twins". Machines. 2022 DOI https://doi.org/10.3390/machines10070577

4. Details of the impact (indicative maximum 750 words)

The research in the case of IMMSM has been a collaborative and incremental effort spanning over a twenty-year period. Over the past decades, our research focus has evolved alongside the rapid pace of technological advancements, transitioning to a more interdisciplinary approach. This is

reflective of the changing competition landscape of manufacturing, which now encompasses not only technological evolution but also the evolution of management concepts and practices.

Furthermore, our research extends also beyond the manufacturing sector, as technological advancements developed in manufacturing can be implemented across various industries, yielding significant effects and contributing to value creation and business generation. Our research therefore focuses on the intersection of technological development within the manufacturing industry and endeavours to transfer technological gains from this sector to others, such as health, aquaculture, transportation, and tourism.

The beneficiaries of our research extend beyond academia, universities, and research institutions to include industries across various sectors as well as local and regional authorities. Inspired and driven by observed challenges in industries and local communities, our research translates these challenges into structured research questions and diverse research applications. The applied industrial cases undergo meticulous situation mapping to establish a robust foundation for arguing the relevance of research and verifying the soundness of technical solutions generated. Furthermore, our publications made based on these industrial cases disseminate research results to peers in academia. We also host seminars and workshops tailored for non-research audiences to disseminate information and raise awareness of the technical benefits, thereby expanding the impact of our research in non-academic society.

Our impact on academic society is reflected in our publication record:
https://app.cristin.no/projects/show.jsf?id=2696114

Our impact on other sectors and the general public can exemplified by public talks such as:

- **Wei Deng Solvang**. "What can the health service learn from logistics solutions in the manufacturing industry?". Future Health Service v. 2.0 Interaction, innovation and preparedness. Health professional and health policy conference. September 2020.
- **Wei Deng Solvang.** "The supply chains of the future - what Nordic cooperation can contribute to building a strong competence network within 3D metal printing". Industry webinar "3D printing - a new industrial adventure in the north?". 2020

Some more recent disseminations and our channelized communication can also be tracked through news archive.

5. Sources to corroborate the impact

1. Impact on academia: https://universitetetitromso-my.sharepoint.com/personal/wso008_uit_no/Documents/1.%20FoU/1.%20IMaLog/FoU%20evaluering%202023/Vedlegg2/ImpactCase-UiT_DeptIndustrialEngineering.pdf
2. Impact through dissemination: https://uit.no/research/arclog/newsarchive
3. Impact through TRINITY network: Homepage - Trinity Innovation Network https://trinityrobotics.eu
4. Impact through I2AM community: https://fmt.kapsi.fi/i2am/
5. European Commission Innovation Radar program "discover great EU- funded Innovations": Department of Industrial Engineering specific results:
   - Industrial system remote control through OPCUA server with general WEB-GUI (https://innovation-radar.ec.europa.eu/innovation/52654)
   - Virtual reality programming of a manufacturing cell (https://innovation-radar.ec.europa.eu/innovation/52628

Impact case: UiT_IAP_1

Institution: Department of Automation and Process Technology (IAP-IVT)
Administrative unit: Department of Automation and Process Technology (IAP-IVT)
Title of case study: Bridging Theory with Practice-Multiphysics Inspired Viscosity-Density Sensor
Period when the underpinning research was undertaken: 2017-2020
Period when staff involved in the underpinning research were employed by the submitting institution: 2017-2020
Period when the impact occurred: 2020-ongoing

1. Summary of the impact

The viscosity-density sensor, a product of multiphysics innovation, was collaboratively developed by academia (UiT-The Arctic University of Norway and ZHAW-Zurich University of Applied Sciences) and Rheonics GmbH, marking a significant advancement in fluid flow and control across various industries. Leveraging advanced multiphysics simulations and engineering, this technology has revolutionized in-line process monitoring, control, and optimization by providing accurate, real-time measurements of fluid properties. Its application in industries such as oil & gas, food processing, pharmaceuticals, and petrochemicals highlights its crucial role as a breakthrough in fluid sensing and management, showcasing the essential role of multiphysics in fostering innovation.

2. Underpinning research

The research insights pivotal to this case study originate from the interdisciplinary field of multiphysics, focusing on the intricate relationship between fluid viscosity, density, and their impact on industrial processes. These findings underscore the development of a sophisticated viscosity-density sensor capable of real-time, precise monitoring and control of fluid properties. This technological advancement, born from the collaboration between academia and industry, leverages complex multiphysics simulations to address real-world challenges in fluid dynamics. The research not only bridged theoretical physics with practical engineering but also highlighted the sensor's vast applicability across various sectors, including oil & gas, food processing, pharmaceuticals, and petrochemicals. By enabling more efficient process control, the research contributes significantly to operational efficiency, product quality improvement, and environmental sustainability, demonstrating a direct link between academic insights and tangible industrial impact.

The underpinning research conducted by the IAP-IVT, in collaboration with Rheonics GmbH and the Zurich University of Applied Sciences (ZHAW), was significantly supported by the Innosuisse - Swiss Innovation Agency Project 27254.1 PFIW-IW during the period of 2017-2020.

The mentioned research was carried out from 01.07.2017 to 04.12.2020.

The key researchers are Hassan Abbas Khawaja (main PhD supervisor, Associate Professor and Research Group Leader) and Daniel Brunner (PhD Candidate)

Hassan Abbas Khawaja has been promoting Multiphysics Simulation by offering TEK-8015, 10ECTS PhD Course Multiphysics Simulation.

3. References to the research

Daniel Brunner, Hassan Khawaja, Mojtaba Moatamedi, Gernot Boiger, CFD modelling of pressure and shear rate in torsionally vibrating structures using ANSYS CFX and COMSOL Multiphysics. The International Journal of Multiphysics, 2018, 12(4): pp. 349 - 358.
http://dx.doi.org/10.21152/1750-9548.12.4.349

Daniel Brunner, Joe Goodbeard, Klaus Hausler, Sunil Kumar, Gernot Boiger, Hassan Khawaja. Analysis of a Tubular Torsionally Resonating Viscosity–Density Sensor. Sensors, 2020, 20(11).
http://dx.doi.org/10.3390/s20113036

4. Details of the impact

The research that underpinned the development of the advanced viscosity-density sensor made a distinct and material contribution to the impact by integrating comprehensive multiphysics simulations with practical engineering applications. This interdisciplinary approach, supported by the collaboration between IAP-IVT, Rheonics GmbH, and Zurich University of Applied Sciences (ZHAW), facilitated by funding from the Innosuisse - Swiss Innovation Agency Project 27254.1 PFIW-IW, was instrumental in bridging the gap between theoretical physics and real-world industrial challenges.

The research utilized advanced simulations to understand the complex interactions between fluid dynamics, viscosity, and density under varying operational conditions. These simulations, based on multiphysics principles, allowed for the prediction of fluid behavior under resonance in a way that traditional methods could not achieve. This predictive capability was crucial for the design and development of sensors that could provide accurate, real-time data on fluid properties, thereby enabling industries to monitor and adjust their processes with unprecedented precision.

The collaborative nature of the project ensured that the research was grounded in real-world applicability. Rheonics GmbH's expertise in sensor technology, combined with the academic prowess of IAP-IVT and ZHAW, ensured that the research outputs were not only innovative but also practical and scalable. This synergy between academia and industry was pivotal in translating complex theoretical models into tangible products that could be deployed in various industrial settings.

The research addressed a significant gap in the market for robust, reliable, and accurate viscosity-density measurement tools. By developing a sensor that could operate under the harsh conditions of different industrial environments—ranging from the high pressures and temperatures of the oil and gas sector to the stringent hygiene standards of the food and pharmaceutical industries—the project made a substantial contribution to improving process control, quality assurance, and environmental sustainability.

The project's impact was magnified by its timing and relevance to industry needs. In an era where efficiency and sustainability are paramount, the ability to precisely control and optimize industrial processes is invaluable. The research underpinning the viscosity-density sensor has provided industries with the means to achieve these goals, demonstrating the power of combining multiphysics simulations with practical engineering to solve complex problems and drive innovation.

The research conducted by IAP-IVT, in collaboration with Rheonics GmbH and ZHAW, underpinned by Innosuisse funding, has made a distinct and material contribution to industrial process optimization. By harnessing the principles of multiphysics in a practical, application-focused manner, the project has led to the development of a critical technological advancement in fluid

sensing, with widespread implications for efficiency, quality, and sustainability across multiple industries.

The impact of the research developed through the collaboration between IAP-IVT, Rheonics GmbH, and Zurich University of Applied Sciences (ZHAW) continues to unfold since 2020. For a comprehensive understanding of how this innovative technology is being applied across various industries, enhancing operational efficiencies, and contributing to sustainability goals, please explore the solutions provided by Rheonics at their official website: https://rheonics.com/solutions/. This resource offers insights into the diverse applications of the viscosity-density sensor technology, showcasing its relevance and utility in addressing complex industrial challenges.

5. Sources to corroborate the impact

Rhenoics GmBH official website: https://rheonics.com/

Daniel Brunner PhD Thesis: https://hdl.handle.net/10037/19731

TEK-8015 Multiphysics Simulation, 10 ECTS course offered to PhD students: https://uit.no/education/courses/course?p_document_id=822267

Impact case UiT_IAP_2

Institution: UiT The Arctic University of Norway
Administrative unit: Department of Automation and Process Engineering
Title of case study: Blue Technology
Period when the underpinning research was undertaken: 2020-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2020-2022
Period when the impact occurred: 2012-2024

1. Summary of the impact

At the Institute for Automation and Process Engineering (IAP) research and scientific advisory activity within blue technology has yielded significant outcomes extending beyond academic circles, notably in crucial domains as: public policy, environmental management, food quality, and industrial animal welfare. These initiatives encompass industrial seafood production and marine noise pollution, encompassing factors such as ammunition and explosive residues in aquatic environments. Both spheres of investigation are closely intertwined with aquaculture and fisheries, exerting considerable influence on the national economy.

Underpinning research

Over the past years, IAP has actively engaged in research collaborations with the Norwegian Defence Research Establishment (FFI) focusing on underwater explosives (Kvadsheim *et al.* 2022, 2000). This involvement extends to participation in initiatives such as the JPI Ocean Munition in the Sea program and serving as a national expert in the knowledge hub. This research is pivotal for comprehending the impacts of high-pressure and sound on marine ecosystems.

It has become evident that the use of explosives and subsequent remediation efforts in the marine environment can inflict significant harm on aquaculture fish populations, leading to substantial economic losses for both industries and society at large. Furthermore, the adverse effects of sound and pressure waves on aquatic life, including disruptions to spawning and juvenile habitats, are increasingly recognized.

In light of these concerns, IAP contributes annually to the advice report from the Institute of Marine Research (HI) on Anthropogenic Noise in the Sea (Sivle *et al.* 2022). Effective governmental management of marine environments hinges on robust research supported by high-quality data. Therefore, advancements in measurement science, particularly within the realm of Blue Technology, are essential to ensuring research integrity.

Notably, IAP's research contributions extend beyond explosives and environmental impacts to encompass industrial animal welfare and stunning procedures within the aquaculture and fishery sectors. Ongoing projects focusing on crustaceans (Svalheim *et al.* 2022) and cephalopods, alongside those related to salmonids and lumpsucker, underscore the breadth of research interests within this domain. The outcomes of these endeavors will inform regulatory frameworks in Norway and the EU, with the Norwegian Food Safety Authority relying on insights provided by IAP researchers.

Collaborating closely with NOFIMA, IAP is at the forefront of electrostunning research in Norway. This research is instrumental in shaping public policies and ensuring food quality

standards within the aquaculture industry. Of particular importance are investigations into electrical parameters such as impedance and frequency spectrum, complemented by electroencephalogram (EEG) studies (van de Vis *et al.* 2023), which deepen our understanding of stunning procedures and their impact on animal welfare.

IAP has actively participated in the development of marine technology, including instrument platforms and drones (Aguzzi *et al.* 2020), to enhance research capabilities. Subsea instrumentation and instrumentation concept for measurements of environmental parameters is implemented in courses at IAP, which give a positive contribution to both research and industry in Noth Norway. As a central educational institution in North Norway IAP has a responsibility to educate the students with examples form cutting edge research, a task we are delivering on. Our student's knowledge is IAP most important contribution to the society and industry.

3. References to the research

Aguzzi, Jacopo; Albiez, Jan; Flögel, Sascha; Godø, Olav Rune; Grimsbø, Endre; Marini, Simone; Pfannkuche, Olaf; Rodriguez, Erik; Thomsen, Laurenz; Torkelsen, Terje; Valencia, Javier; López-vázquez, Vanesa; Wehde, Henning; Zhang, Guosong.
A flexible autonomous robotic observatory infrastructure for bentho-pelagic monitoring. *Sensors* 2020 ;Volum 20.(6) s. -
NORCE UiT HAVFORSK

Kvadsheim, Petter Helgevold; Søvik, André Adelsten; Rokke, Eirik; Kolstrup, Marianne Lanzky; Forland, Tonje Nesse; Pedersen, Geir; Grimsbø, Endre; Dale, Ole Bendik; Cao, Yanran; Stene, Anne; Smedsrud, Morten.
Risiko for skade på laksefisk i omkringliggende oppdrettsanlegg ved etablering av undervanns-skytefelt på Korsnes Fort. FFI-RAPPORT 22/00814. : Forsvarets forskningsinstitutt (FFI) 2022 (ISBN 978-82-464-3401-8) 102 s.
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Kvadsheim, Petter Helgevold; Forland, Tonje Nesse; de Jong, Karen; Nyqvist, Daniel; Grimsbø, Endre; Sivle, Lise Doksæter.
Effekter av støyforurensning på havmiljø - kunnskapsstatus og forvaltningsrådgiving FFI-RAPPORT 20/0105. : Forsvarets forskningsinstitutt 2020 (ISBN 978-82-464-3262-5) 99 s.
FFI HAVFORSK

Sivle, Lise Doksæter; Forland, Tonje Nesse; de Jong, Karen; Pedersen, Geir; Zhang, Guosong; Kutti, Tina; McQueen, Kate; Wehde, Henning; Grimsbø, Endre.
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NOFIMA UiT

4. Details of the impact

IAP's primary research contribution, with significant implications for governmental decisionmakers and the Norwegian industry, revolves around industrial stunning procedures in the aquaculture and fishery sectors (Andres *et al.* 2022). Over the years, insights from researchers, including those now affiliated with IAP, have been instrumental in shaping regulations in Norway. This includes providing research support to the Norwegian Food Safety Authority, whose formal recommendations serve as the cornerstone of national regulatory frameworks (Slinde *et al.* 2013).

A critical quality issue in the aquaculture industry is the occurrence of hemorrhages leading to blood spots in salmon fillets, affecting approximately 2-3% of the production. Therefore, it is obvious that even small improvements in this area can yield substantial economic benefits. Earlier research conducted by one of IAP's researchers (Grimsbø *et al.* 2014) demonstrated the importance of frequency spectrum in preventing such damages. Although this issue remains partly unresolved, research and advisory efforts given by IAP aim to address it and has improved the situation.

In 2022, IAP made significant investments in new equipment to bolster research efforts in this domain, becoming the sole entity capable of analyzing signal frequency spectra. A major challenge in experiments involving animals is minimizing the use of research animals. This is particularly pertinent in research on stunning procedures, where identifying the correct electrical parameters presents difficulties. Previous publications (Grimsbø *et al.* 2016) by an IAP researcher outlined a method for determining the optimal frequency range for electrical stunning, thereby reducing the need for live animal testing. Additionally, the acquisition of an apparatus for measuring electrical impedance in 2021 has dramatically decreased the reliance on live animals, allowing for determination of the electro-stunning frequency range without using live animals.

Furthermore, advancements such as the method for measuring voltage over the animal's brain (van de Vis *et al.* 2023) have further reduced the need for live animals in research. Ongoing projects focusing on crustaceans, cephalopods, salmonids, and lumpsuckers, in collaboration with NOFIMA, solidify IAP's position as one of the leaders in electrostunning research in Norway. This research, encompassing electroencephalogram (EEG) studies, holds significance for both public authorities and food quality standards in the aquaculture industry.

The broader research agenda of industrial animal welfare poses challenges in both the aquaculture and fishery sectors. IAP's involvement in the Catch Welfare Platform (CWP) underscores its commitment to addressing these challenges at an international level (Svalheim *et al.* 2023).

Additionally, IAP's engagement in the JPI Ocean initiative Munition in the Sea, particularly as a national expert, underscores a crucial aspect given Norway's numerous dumpsites containing explosives and chemical warfare agents (Campana *et al.* 2016). Collaborations with organizations such as FFI and HI, including participation in advising the Norwegian Environment Agency (Kvadsheim *et al.* 2020), highlight IAP's approach to addressing the challenges posed by explosives in the marine environment (Grimsbø *et al.* 2018).

Recognizing the potential negative impacts of sound and pressure waves on aquatic life, IAP remains actively involved in initiatives such as the annual report about advice from the Institute of Marine Research on Anthropogenic Noise in the Sea (Sivle *et al.* 2022). This research activity underscoring the importance of measurement science within the realm of Blue Technology (Aguzzi *et al.* 2020; Pedersen *et al.* 2019). These efforts are integral to maintaining the quality and integrity of research within the marine sciences.

5. Sources to corroborate the impact

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HAVFORSK

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Electrical stunning and killing of lumpfish with commercial waterbath and dry stunners. Tromsø: Nofima AS 2024 (ISBN 978-82-8296-777-8) 11 s. Nofima rapportserie(7/2024)
AKVAPLAN NOFIMA UiT

UiT, Department of Computer Science, Impact case #1

Institution:	University of Tromsø – The Arctic University of Norway (UiT**)**
Administrative unit:	Department of Computer Science (IFI)
Title of case study:	Health research
Period when the underpinning research was undertaken:	2012-2022
Period when staff involved in the underpinning research were employed by the submitting institution:	1985-2022
Period when the impact occurred:	2012-2022

1. Summary of the impact

Tromsø is not only Norway's undisputed capital for Arctic research, but the city is also home to Norway's largest research environment on ICT in the health sector. The city has gradually become a national leader and internationally recognized for its commitment to and work with telemedicine and e-health. The CS Department has given substantial contributions to this development as a supplier of faculty members (part-time or full-time), MSc and PhD candidates with a background in health informatics, been PIs and partners in research projects. We have established the interdisciplinary *Corpore Sano Centre*[1] to identify and investigate *novel CS research problems rooted in complex medical* domains. We were technology area leader of the large strategic research initiative *High North Population Studies (BiN), and partners in the Center for Research Based Innovation (SFI) Visual Intelligence and the Center for New Antibacterial Strategies*. Finally, former graduates have founded companies like DIPS, and Norwegian Health Network, and recently several startups.

2. Underpinning research

The **Cyber Security Group** (CSG) is researching the whole vertical software stack in distributed computing. Notably, we have established and direct the interdisciplinary **Corpore Sano Centre**[2] collaborating with sports science, medicine, law, and psychology to identify and research *novel CS research problems rooted in complex medical* domains. A novel and potentially high-impact Corpore Sano example from the more clinical medical domain, is that CSG has contributed for over a decade with novel AI systems in the gastroenterology domain. Notably, we have produced a series of high impact, widely referenced real-time analysis systems [1] and open datasets in the gastroenterology domain [2].

The **Health Informatics and -Technology (HIT) group** was crucial when landing Tromsø Telemedicine Laboratory (TTL) in 2007, one of the first 14 centres for research-based innovation (SFI) funded by the Research Council of Norway. The Telemedicine Centre at UNN became the host institution for TTL. Professor Gunnar Hartvigsen became center director of TTL. The focus of TTL was on providing research that supports the development of technologies for personalized health, empowering elderly and people with chronic and lifestyle related diseases to manage their own health and daily living in order to unload the pressure expected to come on the healthcare services in the future and enable treatment at the lowest effective level of care. TTL had tremendous effect on the HIT group's research, particularly on diabetes. Our Diabetes Diary for self-management of diabetes has been downloaded by >20.000 people and is available in Norwegian, English and Czech [3]. Other results included a dedicated smart watch app [4] and tools for optimizing the glucose level, like a juice machine [5].

[1] https://site.uit.no/corporesano/
[2] https://site.uit.no/corporesano/

IFI was a partner in the UiT strategic initiative **High North Population Studies (BiN)** 2018-2021 with its application areas; technology (IFI's responsibility), lifestyle and health, social inequity in health, child and adolescent health, and environmental poisons. Most of IFI's research groups have been contributors to this initiative. The initiative with a total budget of 96 MNOK was highly interdisciplinary, spanning across 4 faculties (health, science & technology, fishery & economy, humanities). Most PhDs were supervised by cross-disciplinary teams. Until December 2021, the formal termination of the initiative, BiN had created 49 journal articles and over 30 conference contributions. The last PhD is expected to defend middle of 2025. BiN's research focused on population health and its predictors, based on data from different population studies, especially the Tromsø Study. Head of the BiN technology area was Professor Alexander Horsch who has a background in sensor-based physical activity research also from Germany [7-9].

The **Health Data Lab** are partners in SFI Visual Intelligence where complex health data analysis is one of four innovation focus areas. The lab has also contributed to large epidemiology research projects such as Norwegian Women and Cancer, BiN, Centre for New Antibacterial Studies (CANS) and will be a part of the upcoming 8th wave of the Tromsø Study [10-12].

Key researchers:

1. Professor Gunnar Hartvigsen: Research group leader of the HIT group (1998-); Centre director of TTL (2007-2015); Professor II at UNN (2000-2018).
2. Professor Eirik Årsand: Member HIT group (since 2002); Professor CS Dept. (since 2018); Head of diabetes research group at Norwegian Centre for e-health research (since 2000); PI diabetes in TTL (2007-2015).
3. Professor Alexander Horsch: Member HIT group (since 2002); Adjunct Professor CS Dept. (2005-2009); Professor CS Dept. (since 2010); head of technology area in BiN;
4. Assoc. prof. André Henriksen: Member HIT group (since 2016); Ass. professor CS Dept. (since 2021)
5. Professor Dag Johansen: Research group leader of the CSG group (1994-); Center Director Corpore Sano (2015-)
6. Professor Håvard Dagenborg: Section Leader HIT&CSG (2021-)
7. Professor Lars Ailo Bongo: Group leader of HDL; Member: SFI Visual Intelligence, CANS, BiN; co-founder of Medsensio AS.
8. Associate Professor Einar Holsbø. Member HDL, CANS, BiN.
9. Associate Professor Vi Tran. Member: HDL, CANS.
10. Associate Professor Edvard Pedersen. Member: HDL.

3. References to the research

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4. Details of the impact

The Tromsø community's research and development within ICT in the health sector was put on the national map already in the 70s when the district doctors in Balsfjord municipality could use Norway's first electronic health record (EHR) for the primary health service. The Balsfjord system was developed at the Department of Computer Science, UiT. The X-ray department at UNN's (former RiTø) need to be able to transfer large X-rays from hospitals in Finnmark to Tromsø formed the prelude to what is today the Norwegian Health Network, a state-owned company that ensures that all actors in the health sector can communicate through a closed health network. The Department of Health Network Operations is still located in Tromsø. In 1987, DIPS was founded by a graduate from our department. Today, DIPS is the leading electronic health record at Norwegian hospitals with 80% market share. Through the establishment of the Norwegian Centre for Telemedicine more than 30 years ago, the city has gradually become a national leader and internationally recognized for its commitment to and work with telemedicine and e-health.

In 2007, a new chapter started for the Tromsø community's focus on ICT in health. In strong competition with research communities across the country, the Telemedicine Centre at UNN became the host institution for the Tromsø Telemedicine Laboratory (TTL), one of the first 14 centres for research-based innovation (SFI) funded by the Research Council of Norway. Professor Gunnar Hartvigsen headed the grant application process and became center director. Several faculty members and a few former PhD and MSc students from our department joined TTL.

The focus of TTL was on providing research that supports the development of technologies for personalized health, empowering elderly and people with chronic and lifestyle related diseases to manage their own health and daily living to unload the pressure expected to come on the healthcare services in the future and enable treatment at the lowest effective level of care. In TTL, UNN and UiT were joined by several of the pioneers in this field. This gave a real boost to research in ICT in health, and as host of TTL in 2013, the Telemedicine Centre was able to adorn itself with the title of UNN's best research environment.

The **Health Informatics and -Technology (HIT) group** was established in 1998 with the name Medical Informatics & Telemedicine (MI&T). The group was from the beginning closely connected to the then Norwegian Centre for Telemedicine (NST) at the University Hospital of North Norway (UNN). Several of the MI&T group's members held full or part-time positions at NST. From around the year 2000, most of the research in the MI&T group took place together with researchers from NST and UNN. The group's master's and PhD students also had their daily work on the premises of

TTL had tremendous effect on the HIT group's research, including increased quality and quantity of our research, increased internationalization, increased number of European projects, increased number of publications with international co-authors, increased visibility world-wide.

HIT research group is responsible for teaching and supervision in telemedicine and e-health at the Department of Computer Science. Over the past 20+ years, research in the HIT research group has contributed with research in diabetes, cognitive impairment, sickle cell anaemia, health sensor validity, physical activity epidemiology, public health studies and public health research. The projects use various medical sensors, telemedicine equipment and health applications. The research group collaborates with national and international researchers and research groups in health and technology.

When Minister of Education and Research Torbjørn Røe Isaksen presented the "Research Barometer 2016" in May 2016, there were three research areas in medicine and health in Norway he praised for his research efforts: cancer research in Norway (by Oslo cancer cluster), the development of a vaccine against the Ebola virus (by Folkehelseinstituttet), and the focus in Tromsø on m-health in diabetes. The latter was research done in the HIT group at our department.

Together with the affiliated group members at the Faculty of Health Science, we have since 2018 been working on a large-scale infrastructure for recording of health and physical activity data during the next version of the Tromsøundersøkelsen (Tromsø Study), which is a large population study in Tromsø that has been going on since 1974. In the next Tromsø study, the plan is to use an infrastructure for recording as much health and physical activity data as possible from as many people as possible over as long time as possible. The infrastructure is based on our previous and ongoing project in "physical activity", "diabetes", as well as ongoing PhD projects on digital twins.

The **Cyber Security Group** (CSG) is researching the whole vertical software stack in distributed computing. Notably, we have established and direct the interdisciplinary **Corpore Sano Centre**[3] collaborating with sports science, medicine, law, and psychology to identify and research *novel CS research problems rooted in complex medical* domains. We can illustrate this with an ongoing subproject, the philanthropic funded FFRC[4], and probably the most visible international research center world-wide of its kind with its focus on *gender-specific* health and sports performance issues. Our main initial motivation was that less than 5% of sport science and health research literature focused on *female athletes*, and we have now obtained new and fundamental insights and knowledge on highly relevant performance factors that influence sustainable development and health of *female* elite football athletes. This includes, e.g., no/little football-practical impact of traditional Gold-standard male weightlifting; surprisingly large problems with carbo deprivation

[3] https://site.uit.no/corporesano/
[4] Female Football Research Centre: https://uit.no/research/ffrc

during season leading to relative energy deficiency in sport (RED-S) syndrome with poor health and declining athletic performance; and significant psychological gender differences vs males in similar settings. We are using 24/7 quantification technologies (e.g. sports clock, wearable IoT Altigraph, cellular, GPS tracker, DEXA scanner, video cameras) for cohorts between 20 to 300 female elite athletes, and our analyses include multi-modal deep learning (AI).

A novel and potentially high-impact Corpore Sano example from the more clinical medical domain, is that CSG has contributed for over a decade with novel AI systems in the gastroenterology domain. Notably, we have produced a series of high impact, widely referenced real-time analysis systems [1] and open datasets in the gastroenterology domain [2]. This collaborative research with our colleagues in the Holistic Systems department at SimulaMet in Oslo, besides producing papers and datasets already referenced *thousandfold* times, has also resulted in a **med-tech start-up** in Oslo, Augere Medical Ltd[5].

The **Health Data Lab (HDL)** focuses on providing methods, systems, and tools for advanced health data analysis and utilization. The computer systems built by the lab are used in research projects, infrastructure, and commercial products. The open-source code, open access datasets, and open models published by HDL have many forks and downloads. Former and current lab members have also founded the Medsensio and Woid medtech startups, and HDL collaborates with startups such as Lifeness and established companies such as DIPS. In summary, HDL is an important partner in many of the large epidemiology, medicine, and machine learning projects. In addition, the lab is an important academic collaborator for medtech startups in Norway. Two existing examples are first the technology described in (5) is to be verified at the cardiology department at UNN, integrated into the Medsensio service stack, and used to collect data in the Tromsø 8 population study. Second, one of the HDL PhD students (Pavitra Chauhan) has a co-supervisor from DIPS (Dr. Bjørn Fjukstad) and her research on the use of synthetic data to develop clinical decision support systems (CDSS) complements (6) the OpenDIPS platform and the results will be utilized by proposed new Norwegian research infrastructure for CDSS tool development, deployment, and evaluation.

5. Sources to corroborate the impact (indicative maximum of ten references)

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UiT, Department of Computer Science, Impact case #2

Institution:	UiT The Arctic University of Norway
Administrative unit:	Department of Computer Science (IFI)
Title of case study:	Distributed systems - Sustainability
Period when the underpinning research was undertaken:	2012 – 2022 (and ongoing)
Period when staff involved in the underpinning research were employed by the submitting institution:	Same period
Period when the impact occurred:	Same period, scaled up from 2020

1. Summary of the impact (indicative maximum 100 words)

We have investigated, developed, and experimented with a series of novel distributed systems prototypes. Novelty stems much from the unique characteristic and limitations of the geographical proximity these systems are built for, the very isolated, resource-poor Arctic Ocean and Arctic Tundra without the civil infrastructure like power and network connectivity normally taken for granted. Our projects are central to inter- and transdisciplinary projects in the Arctic and might provide high impact solutions in other domains (e.g., sustainable management of commercial harvesting of vital fish resources, monitoring on-the ground data from the Arctic tundra for other sciences to use).

2. Underpinning research / 4. Details of the impact

The United Nations' Conference on Sustainable Development ("Rio+20") considered technology, science, and capacity building as major pillars to eradicate poverty and reorient current unsustainable development trajectories. According to the UN, affordable *technological solutions* must be developed and disseminated widely by 2030. The UiT Computer Science department has several research groups that address *sustainability through such digital technology solutions*.

Sustainable fishing industry

The larger context for research in the **Cyber Security Group** (CSG) is that a global population depends on a *sustainable fishing industry*, which is reflected in several of the recent 17 UN Sustainable Development Goals (SDGs) to end poverty, protect the planet, and ensure prosperity for all. SDG #14 states this goal clearly: *"To conserve and sustainably use the oceans, seas, and marine resources for sustainable development."*

Closely related UN SDGs motivating our research include strengthened food security (SDG #2), promotion of sustainable economic growth (SDG #8), sustainable consumption and production (SDG #12), and strengthened global partnerships for sustainable development (SDG #17).

SDG #14 and these related SDGs aim to conserve and sustainably use the oceans and their resources for the benefit of people and the planet. This includes protecting marine ecosystems, *preventing* pollution and *overfishing*, and increasing scientific understanding of the oceans. Overfishing is a serious global problem, and uncontrolled and illegal harvesting of these important food resources has led to the collapse of several ecosystems at sea. The Arctic Ocean is important for harvesting sea proteins to a global population (value of fish export from Norway in 2023 amounts to ~170 billion NOK), and commercial fishing by Norwegian, Russian, and EU country fleets totals boats in the order of thousands during main seasons. Between 1-2% of these boats are inspected manually by the Norwegian Coast Guard, which creates opportunities for uncontrolled, illegal overfishing of a depleting fish population.

Motivated by the UN sustainability focus and the Norwegian Governmental report NOU 2019:21 about next generation commercial fishing control, CSG has been and is focusing our distributed systems research to support management and control of sustainable commercial fisheries in the

Arctic[1]. This research focus scaled significantly up from 2020, when CSG received a large, *philanthropic gift of 40 M NOK*.

We have started to investigate AI-based *automated surveillance systems* where the goal is to securely detect and report potential illegal activities on board a remote fishing vessel. The system prototypes are developed towards a future AI-supported surveillance model where the entire fleet is connected in a large distributed system. A collection of (1) IoT monitoring devices on-board each fishing vessel will then be feeding data into (2) multi-modal AI-computations performing real-time analysis, and (3) persisting data of relevance for legal investigations in retrospect. Similarly, potential anomalies will be detected, and evidence-based insights and AI-triggered suspicions transferred immediately over (4) low-bandwidth satellite networks to (5) mainland, global surveillance hubs. These hubs will federate data from all edge nodes, the commercial fishing vessels, and analyze the global state of the entire fleet using received data from the individual boats correlated with additional sources (satellite images, AIS signals, mandatory catch reports, quotas, etc.). This analysis can next be formative when scheduling more accurately targeted physical inspections. The distributed architecture is influenced by collaborating stakeholders like, e. g., national eco-crime and ocean surveillance units, and even commercial fishing actors.

The focus of our research has been to investigate and develop ***digital twin inspectors*** that potentially can be deployed on-board all licensed fishing vessels in the Arctic performing local 24/7 surveillance in a *privacy-preserving* manner. This fully automated AI approach is opposed to the current mandatory video surveillance regime recently implemented in, e.g., Denmark where video data is streamed in real-time from all vessels to mainland and manually inspected at central surveillance centers. This approach comes with conflicting issues; it can be characterized as privacy infringing and conflicting mass surveillance, (too) many human inspectors at mainland sites are needed, and it depends on high-bandwidth connections to the (much closer) Danish mainland.

A tenfold times larger Arctic off-shore fleet using low-bandwidth satellite communication to the Norwegian mainland cannot use this resource-demanding approach. The challenging weather conditions in the Arctic that fishing vessels operate in are also a concern we need to consider; a single failure on a computer or an IoT sensor malfunctioning on the remote vessel must not render the complete system useless. This increases the importance of designing a robust and secure system that can tolerate many types of faults but that also can monitor, detect, and remedy adversarial attacks. A hard security problem is that the adversary might be physically onboard the vessel.

Our series of run-time system prototypes and AI applications [1][2][3] have been designed for monitoring and surveillance in these privacy-sensitive, unsecure, and unstable offshore environments. Detection of *anomalies* within real-time data streams is an important task that is useful for remote surveillance monitoring, particularly on-board a remote and isolated trawler in the Arctic Ocean. To be able to perform anomaly detection, *unsupervised* analysis of data can be preferrable since anomalies that should be detected are often changing or are not clearly definable at all. Labelled data, which is necessary for a supervised machine learning solution, is rare or not available yet at all in this domain.

Since serious adversarial attacks can happen by personnel onboard, our run-times have been built with numerous redundancy components and the ability to monitor and control the system from the mainland over satellite links. Flexible access policies at the storage level can provide privacy guarantees for data transfer and access, and encryption schemes are applied to guarantee that forensics data with potential to hold as evidence of illicit activities in court is securely logged.

Key to this research is a new mandatory regulation that must require that licensed fishing vessels must have such a system actively running. We work closely with legal expert scholars and public

[1] https://site.uit.no/arcsecc/sustainability/

sector authorities to make this happen. We have also implemented our prototypes in a *compliance-by-design* perspective (with legal scholars) to ensure that our software is following fundamental human rights, data protection laws, and regulations such as GDPR and the EU AI Act.

Distributed Arctic Observatory

A complete example that shows the impact of the department in understanding important factors impacting northern Norway and discovering how to build this specific type of systems is the Distributed Arctic Observatory (DAO project).

COAT, the Climate-ecological Observatory for the Arctic Tundra, aims at giving "a robust documentation and predictions on climate change impacts on biodiversity, natural resources and ecosystem processes in the Norwegian Arctic". However, the context of the Arctic Tundra, being vast, hard to reach, dangerous, extremely limited in infrastructure (both network and energy), make it extremely complicated to have resilient, connected, frugal and autonomous distributed systems observing the Arctic Tundra. As we speak, less than one per cent of such an ecosystem is observed in-situ (i.e at a very fine grain level, beyond the help of coarse grain observations, like satellites), needed to understand the evolution of specific parameters (e.g, evolution of a certain type of fauna, flora, type of animals, ecological parameters, etc).

The Distributed Arctic Observatory aims at providing architectures, designs, implementations, experimentation and prototypes to give insights to the computer science and interdisciplinary research communities on how to build systems deployed and observing such environments.

The DAO project is motivated by many key challenges, highlighted as current and future challenges for "peace and prosperity for people and the planet" by the United Nations. By building a distributed observatory for an eco-system like the arctic tundra (i.e, endangered, very sensitive to climate change, very isolated in infrastructure and resources), this project directly contributes to goal 13 "Take urgent action to combat climate change and its impacts", goal 15 "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss" (Publication 1, 2 and 3).

Following the discoveries of the DAO-Cyber Physical System, systems in such environments could cover larger areas, gather and crunch more data, be more autonomous and more frugal.

The difficulties creating prototypes is a known challenge. Building prototypes for constrained environments, such as the DAO, is an even harder challenge. To simplify and ease such challenges and its dissemination, we created "UiT's IoT to (extreme) edge testbed". Such a testbed aims at providing a platform for students, researchers and industries to provide and simplify the usage and testing of prototypes (both software and hardware) in such constrained environment, with external monitoring for key metrics like energy consumption.

By building prototypes with off the shelf hardware and making them widely available, the DAO project and the "UiT's IoT to (extreme) edge testbed" contributes to goal 17, where "affordable technological solutions have to be developed and disseminated widely in the next fifteen years".

The research underpinned can be directly included in interdisciplinary research observing environments in hard-to-reach scenarios. We document the proposed results about the architectures, designs, implementations and prototypes with reproducible experimentation, methodologies and results. This is a key asset in creating useful and directly reusable results for other researchers. This documentation is done through multiple papers published in highly recognized and selective peer reviewed international IEEE and ACM conferences, highly ranked in international rankings.

We aim at impacting both researchers in computer science, but also other research fields. It can also impact stakeholders, deciding on how and what should be done next in terms of decisions to, for example, save endangered and difficult to observe eco-systems like the Arctic Tundra.

Such impact on many interdisciplinary fields can be shown by looking at the research papers using our research and citing them. A good example is the paper entitled “Leveraging energy-efficient non-lossy compression for data-intensive applications” cited by papers in computer science, geo-science and environmental research. Another one would be “Trading data size and cnn confidence score for energy efficient cps node communications” cited by papers in system computer science but also industrial informatics. Such wide reachability on recent papers shows a high impact and reusability of our proposed approaches and research.

3. References to the research

(1) Nordmo, T.-A.S.; Ovesen, A.B.; Johansen, H.D.; Riegler, M.A.; Halvorsen, P.; Johansen, D. “Dutkat: A Multimedia System for Catching Illegal Catchers in a Privacy-Preserving Manner”, 2021. In Proc. of the 2021 ACM Workshop on Intelligent Cross-Data Analysis and Retrieval, pp. 57–61 https://doi.org/10.1145/3463944.3469102

(2) Ovesen, A.B.; Nordmo, T.-A.S.; Johansen, H.D.; Halvorsen, P.; Riegler, M.A.; Johansen, D. “File system support for privacy-preserving analysis and forensics in low-bandwidth edge environments”, 2021. Information, 2(10), 430; https://doi.org/10.3390/info12100430

(3) Alslie, J.A.; Ovesen, A.B.; Nordmo, T.-A.S.; Johansen, H.D.; Halvorsen, P.; Riegler, M.A.; Johansen, D. “Áika: A Distributed Edge System for AI Inference”, 2022. Big Data Cogn. Comput., 6, 68. https://doi.org/10.3390/bdcc6020068

(4) Murphy, M.J; et.al. “Experiences Building and Deploying Wireless Sensor Nodes for the Arctic Tundra”,21st IEEE/ACM International Symposium on Cluster, Cloud and Internet Computing (CCGrid), 2021. https://doi.org/10.1109/CCGrid51090.2021.00047

(5) Raïs, I.; Guegan, L.; Anshus, O. “Impact of loosely coupled data dissemination policies for resource challenged environments”, 22nd IEEE/ACM International Symposium on Cluster, Cloud and Internet Computing (CCGrid), 2022. https://doi.org/10.1109/CCGrid54584.2022.00062

(6) Raïs, I.; et.al. “UAVs as a Leverage to Provide Energy and Network for Cyber-Physical Observation Units on the Arctic Tundra”, IEEE International Conference on Distributed Computing in Sensor Systems (DCOSS), 2019. https://doi.org/10.1109/DCOSS.2019.00114

5. Sources to corroborate the impact (indicative maximum of ten references)

Sustainable fishing industry

CEO Svein Ove Haugland, Norges Råfiskelag, +47 908 80 021, svein.ove.haugland@rafisklaget.no

Dr. Ståle Walderhaug, Director SINTEF Nord, Tromsø, Norway (https://www.sintef.no/en/all-employees/employee/stale.walderhaug/) (CSG reference)

Distributed Arctic Observatory

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UiT, Department of Computer Science, Impact case #3

Institution:	UiT The Arctic University of Norway (UiT)
Administrative unit:	Department of Computer Science (IFI)
Title of case study:	Student entrepreneurship
Period when the underpinning research was undertaken:	2015-2022
Period when staff involved in the underpinning research were employed by the submitting institution:	2015-2022
Period when the impact occurred:	2016-2022

1. Summary of the impact

Master students at IFI has co-founded 5 startups in the last 7 years, that have created about 25 new jobs in the private sector, and raised more than 63 MNOK in funding. The department has systemized the support for student entrepreneurship in the form of an innovation lab that is being used as a template at UiT for building culture for entrepreneurship at other departments and faculties. In addition, we use the experiences to nationally increase the number of AI startups through our participation in the NORA.startup network.

2. Underpinning research

Our culture for student entrepreneurship is the result of all research groups at the department contributing to the education of students with skills and confidence to do startups, and to research projects that have formed the technology foundation for the startups. In addition, the creation of the Digital Innovation Lab has provided the support needed to translate research results into viable technology startups.

The 5 startups are the result of 4 varying research projects (the 5th is not based on research from IFI). All startups have a recently graduated master student from IFI as co-founder. Also, all have interdisciplinary teams, and many are based on interdisciplinary research results. **Medsensio** was co-founded by Johan Ravn who developed a machine learning method for classification of abnormal lung sounds. The master's project [results are trade secret] was in collaboration with Tromsø Study 7 [1]. The results of Ravn's and another master's project by Morten Grønnesby (HDL, 2015-2016) were licensed to Medsensio. Later a machine learning method for classifying abnormal heart sounds [2] developed by researcher Per Niklas Waaler (HDL) were also licensed by Medsensio. **Keenious** was co-founded by Frode Opdahl who developed a solution for finding references based on the context of text inputs [trade secret]. **Woid** was co-founded by Mariel Ellingsen. It was her own idea to do a master's project to develop hearing aids based on a set of mobile phone microphones that lead to the creation of Woid [3]. **Abdera** was co-founded by Markus Tiller who did a master's project in SFI Visual Intelligence [4], where he collaborated with the KSAT company [5]. He used the skills learned in his master's to develop the system and moderation tools for a machine learning based detection of hate speech.

Ravn, Grønnesby, Ellingsen, and Tiller were all master students in the Health Data Lab. Ravn, Grønnesby, Waaler, and Tiller did their projects under supervision of Professor Lars Ailo Bongo (2016-2017 and 2021-2022). Ellingsen was supervised by Associate Professor Edvard Pedersen (2021-2022). Opdahl did his master's in the Open Distributed Systems group under supervision of Professor Randi Karlsen (2016-2017). Bongo, Pedersen, and Professor Anders Andersen were academic mentors for Medsensio, Woid, and Keenious in the start.

To increase the number of technology startups from our research project, industry mentor (a one year 20% position) Dominic Riley and Professor Bongo created the Digital Technology Innovation Lab in 2021 [6]. Woid and Abdera are two of the three cases the lab worked on in the pilot year.

3. References to the research

[1]: https://uit.no/research/tromsostudy
[2]: Per Niklas Waaler, Hasse Melbye, Henrik Schirmer, Markus Kreutzer Johnsen, Tom Dønnem, Johan Ravn, Stian Andersen, Anne Herefoss Davidsen, Juan Carlos Aviles-Solis, Michael Stylidis, Lars Ailo Bongo. Algorithm for Predicting Valvular Heart Disease from Heart Sounds in an Unselected Cohort. Front. Cardiovasc. Volume 10 – 2023.
https://doi.org/10.3389/fcvm.2023.1170804
[3]: Mariel Ellingsen. First steps towards solving the café problem. Master's thesis. Dept. of Computer Science, UiT The Arctic University of Norway. June 2022.
https://munin.uit.no/handle/10037/25921
[4]: https://www.visual-intelligence.no/
[5]: Markus Tiller. End-to-end Trainable Ship Detection in SAR Images with Single Level Features. Master's thesis. Dept. of Computer Science, UiT The Arctic University of Norway. June 2022.
https://munin.uit.no/handle/10037/26008
[6]: https://uit-dtil.github.io/

4. Details of the impact

Our work on building a culture for student entrepreneurship at IFI has resulted in Digital Innovation Lab [1]. The lab aims to improve the number of successful research-based startups from UiT. We provide an environment and support for pre-commercial projects, where we work on and welcome ideas from researchers in computer science, machine learning, and other fields where computation and software is an essential part. We also welcome software based startup ideas from all students at UiT. We are active in helping students and researchers develop the right startup concept, gain validation and support for the idea, build up a complimenting founder team and advise on prototyping and tech development. The ultimate goal is securing financing for the tech startup and here the Lab team can help with putting together a development plan, financing plan and application pitch for financing.

In Norway, a great source for funding for student entrepreneurs is the STUD-ENT program. Medsensio was the first startup from UiT that received 1MNOK in funding in 2016 [2]. Later Keenious (2017), Pazzinga (2017), Woid (2022), and Abdera (2022) also received 1MNOK in funding. [2] Only 3 other startups from UiT have received STUD-ENT funding.

Later all startups have received soft funding from the Research Council of Norway, Innovation Norway, EU Horizon 2020, and in addition private investors. For example, in 2019, Keenious got a €50.000 EU grant under the "INDUSTRIAL LEADERSHIP - Innovation In SMEs" program [3], and Medsensio was a key partner in the €6.782.267 PyXy.AI project funded by Horizon 2020 [4] in 2020 for COVID-19 medtech development. We are especially proud that Medsenio and Woid received a €75.000 grant from the WomenTech EU [5] that is given to deep-tech start-ups led by women.

All companies have received support from IFI in the form of academic mentors. Medsensio has had an especially close collaboration with IFI. This research collaboration has resulted in 5 publications, 2 presentations at academic conferences, 2 patent applications, and open-source code. Medsensio has also published an open access dataset [6]. The startups have also received other academic

recognition. The co-founder and CEO of Woid, Mariel Ellingsen, was the keynote at the 2023 ACM womenENcoruage conference [7].

Today Medsenio and Keenious are well established companies. Keenious currently has 19 (business-to-business) customers. Medsensio is close to CE marking of their medical technology. Unfortunately, Pazzinga failed. The two newest companies are regarded as promising startups. Abdera won the Arctic Ignite competition in 2022 and received a 500.00 NOK price [8]. In 2023 was selected to join the StartupLab incubator (the best in Norway). We expect these, and future startups from IFI, to have great societal impact both in their products and their contribution to economic growth in Norway.

The five startups have created about 25 new jobs in the private sector, and raised more than 63 MNOK in funding.

The success of our support for student entrepreneurship has been recognized at UiT and nationally. In 2022 UiT established UiT Talent [9] that includes a strategy and funding for innovation activities at UiT. One of five key areas is the establishment of innovation laboratories similar to our Digital Innovation Lab. We expect to take an active role to support the establishment and operation of the new innovation labs, and with the importance of software for most startups, we will be one of the key labs at UiT.

Nationally, we are contributing to research based AI entrepreneurship through our participation in the NORA.startup network where Bongo is on the steering board. NORA.startup is a network of AI researchers, startups, and incubators. We take an active role in building a culture for student entrepreneurship. We have given several webinars on the topic, and for example hosted a workshop on “Founding an AI startup as an AI Researcher” in 2022 [10].

Building a culture for entrepreneurship also requires close collaboration with industry. The innovation lab therefore has two annual events. In the first we invite startup founders to present their experiences to encourage students to do or join startups. In the second event we invite local startups and other companies to pitch master’s projects for our students. This has been a great success and we currently about 10% of the students do an industry master’s.

5. Sources to corroborate the impact (indicative maximum of ten references)

1. Home page of the Digital innovation Lab: https://uit-dtil.github.io/
2. List of STUD-ENT fund recipients at UiT: https://uit.no/forskning/innovasjon/art?p_document_id=710388#modal_712163
3. EU startup grant awarded to Keenious: https://cordis.europa.eu/project/id/878077
4. EU grant where Medsensio is technology provider: https://cordis.europa.eu/project/id/101016046
5. Medsensio and Woid received a grant given to tech companies with female leaders: https://eismea.ec.europa.eu/system/files/2023-04/Women%20TechEU%202022%20companies_final.pdf
6. Medsensio publishes open access data: https://zenodo.org/records/7857970
7. Woid co-founder gives keynote at ACM conference: https://womencourage.acm.org/2023/program/keynote-mariel-evelyn-markussen-ellingsen/
8. Abdera wins Arctic Ignite award: https://www.linkedin.com/posts/abdera-ai_tusen-takk-til-norinnova-as-som-tildelte-activity-6989167334624014336-y6Yq/?originalSubdomain=no
9. UiT Talent with innovation labs: https://en.uit.no/talent

10. NORA.startup event #30: Founding an AI startup as an AI Researcher.
https://www.nora.ai/events/NORAstartup-commercialising-research-2.html

UiT, Department of Computer Science, Impact case #4

Institution:	UiT The Arctic University of Norway (UiT)
Administrative unit:	Department of Computer Science (IFI)
Title of case study:	From Distributed Systems Research to Educational Programs to Societal Challenges, and Back
Period when the underpinning research was undertaken:	1980s-2022
Period when staff involved in the underpinning research were employed by the submitting institution:	1980s-2022
Period when the impact occurred:	1980s-2022

1. **Summary of the impact** (indicative maximum 100 words)

At the Department of Computer Science, University of Tromsø (UiT) - The Arctic University of Norway, a set of carefully implemented strategies and focus on the correct equipment enabling both research and educational programs have been fundamental in enabling the department's long-term impact on society.

Focusing on distributed computer systems, the department is unique in providing both the public and the industry in Northern Norway with graduates at all levels having excellent proficiency in understanding and creating system architectures, system designs, and system implementations. The skills of our graduates are very well received both nationally and internationally. The quality and quantity of the graduates are important for both the public sector, smaller companies, as well as the offices in Tromsø of larger companies like Microsoft Software Development Center Norway, DIPS (health-related software development), and Kongsberg Defence and Aerospace (Space).

2. **Underpinning research** (indicative maximum 500 words)

During 1985-1989 the department made several important formative decisions with lasting effects until today. At the time it was the smallest computer science department at the smallest university of the then four universities in Norway (today there are many more universities in Norway, and both the UiT and the department have grown significantly).

First, the department decided to comprehensively base its educational program on the ACM/IEEE curricula recommendations, and to revise the programs to track changes over time of the recommendations. This was done to benefit from the collective international wisdom on how to structure and select content for a relevant and strong university education in computer science.

Second, the department decided to be strong on systems research in computer science. This was done to increase the systems understanding to be able to do both relevant research and education needed to attack societal challenges and meet the needs of the public sector and private industry for knowledge and proficient employees with excellent skills in understanding the architecture, design, and implementation of software systems at both small and large scale.

Third, the department decided to have a special focus on research and courses on distributed, parallel, concurrent, and interoperable systems. This was done because it was confident that such knowledge would be needed as a platform for most systems in the future.

Fourth, the department decided to be internationally oriented by establishing and supporting contact and collaboration with computer science departments at recognized international universities. This was done to realistically be able to deliver on the other three decisions.

Fifth, the educational programs are closely tied in with the research at the department. Both undergraduate and graduate courses are in particular focused on skills needed to understand and develop the architectures, designs, and implementation of systems at both small and large scale. To further strengthen the link between research and education, all master students are assigned space in the laboratories of the research group advising them. The topics of most bachelor and master projects are taken from ongoing research projects. The skills, insights and experience they gain from such an integration greatly contributes to how rapidly and well they are able to contribute to the public and private sector.

Sixth, in 1986-1992 the Norwegian government had a national program funding new computers and assorted equipment for education in "ICT". The funds assigned to the department were enough to replace some, but not all, of the existing, old, and unsuitable timeshared computers in use in the mid 80s. However, to reap the benefits of modern Unix workstations a new set of courses would have to be developed and maintained. To do this and still teach the courses designed for the old timeshared computers was found not to be a scalable approach for a small department. Consequently, to transition wholly from old to new courses, all the old and limiting computers had to be replaced practically simultaneously.

All the department's research groups participated in the effort of creating and maintaining a paradigm shift of the department's research and its research based educational programs.

Central persons at the department working on these efforts in various roles were Profs. Otto Anshus, Tore Brox-Larsen (retd.), Gunnar Hartvigsen, Dag Johansen.

3. References to the research (indicative maximum of six references)

The reference https://rapport-dv.uhad.no/views/Kandidatunderskelsen2019_2021Mv_2/Arbeidstilknytning has statistics maintained by UiT and indicates that the education given by the Department of Computer Science (IFI) is held in high regard by the students and prepares them well for later job positions. For the period 2018 to 2022, 94% of the graduates who responded to a questionnaire, answered that they were satisfied or very satisfied with the education they received, while 88% answered that they were satisfied or very satisfied with the job position they got after graduation. For the UiT as a whole, the corresponding numbers are 84% and 84%.

Official data about students graduating from UiT in 2019/2021 shows that all graduates from the Department of Computer Science have a job. 79% work in private companies, and 71% work directly in the field of "ICT/data, tele and satellite communication". One to three years after graduation, as many as 45% of the graduates hold a leader position within the company they work at and have responsibilities for the company's results.

Of all the respondents from the department, about 93% got a master level degree.

The Department of Computer Science has an alumni association (*CandiData*). The department has asked its graduates using the CandiData's distribution list about their opinions about the education they got from the department. While such a user study is not a scientific study, and the results should be used with caution and in general, it allows the graduates to express their opinions.

The answers indicate the increasing trend in how many the department graduate now vs. earlier. About half of the graduates answering graduated during the period 1970-2010 (40 years), while the other half graduated during 2012-2022 (10 years). This is a ratio 1:4.

The Department asked its graduates to answer their agreement with a set of positive statements about the quality and benefit of the education they got. They could answer with *agree*, *perhaps*, *disagree*.

Out of seven questions, five had over 80% *agrees*, one had about 72% *agrees*, and one had 45% *agrees*. The departments education is clearly held in high regard.

When asked, "*In my opinion IFI has taught me skills of relevance to my position»*, almost 87% answered agree. When asked «*In my opinion I have contributed significantly to the implementation of one or several systems made by my employers»*, 88.3% answered *agree*.

The question with the lowest number of agrees was: "*In my opinion I have contributed significantly to my employer's strategic direction*». Here, 45% answered *agree*, and 42% *perhaps*. It is outstanding that so many of the department's graduates clearly contribute significantly to the *strategic* direction of the company they work for. In addition, the answers show that the graduates contributed greatly also to the architecture and implementation of the products developed by the companies they work for.

We were happy to see that in the graduate's opinion their employer valued them greatly (85% agrees).

The graduates were also asked to leave any comment they wanted the department to hear. In particular, the courses on operating systems, parallel systems, database systems, and distributed systems are mentioned as having provided the graduates with a strong knowledge in systems, and that this has been very valuable for their activities. Also, the systems approach and strong emphasis on practical skills from creating architectures to doing implementations were mentioned as a distinguishing characteristics of the department.

4. Details of the impact (indicative maximum 750 words)

Even with the extra funds from the government to purchase computers, the department's ambition to do an educational paradigm shift going from timeshared computers to high-end Unix workstations with high-resolution color displays allowing for much more hands-on course assignments with prototyping and doing performance measuring experiments at all levels, was in danger of being postponed several years.

The department decided that the solution was to make a focused effort to find a vendor or manufacturer who was willing to participate in fulfilling the department's ambition. Eventually, such a vendor and manufacturer were found, and the department got huge donations of high-end workstations allowing it to provide high-end workstations for all its courses, and for its master and PhD students. To be able to develop and maintain the new courses needed, the faculty and technical staff also were given new workstations. This protocol was maintained over the years the governmental program lasted and allowed the department to purchase and receive donations of increasingly more powerful workstations, tracking the progress in technology.

This made it possible for the department to completely phase out old teaching platforms based on time-sharing multi-user computers. Instead, many modern high-end workstations running Unix was introduced at every level of the educational programs. These enabled the department to do courses with significantly more hands-on assignments of much greater system complexity than before.

For all courses the single-user Unix workstations made programming assignments much more efficient to develop, and they could therefore be made more complex with greater learning outcome. Courses on distributed systems, distributed databases, parallel systems, and concurrent systems benefitted immensely because they now had a network of computers to do much more realistic assignments and projects on.

The course on operating systems was over time developed into a set of seven projects creating a small operating system. The students are guided in developing all the fundamental operating system abstractions and their implementations from booting a computer to fully functional operating system kernel with virtual memory. The operating system course has been exported to other universities, including the University of Oslo and Princeton University.

The combination of sound strategies and equipment funding revolutionized both the research and education at the department and was the start of its future successes and growth both in research and education.

Being able to successfully implement all five strategies has been vital both for the department, its students, and their employers in the public sector and industry.

Today, the department's graduates at all levels from bachelor to master and PhD, are unique in providing both the public and the industry in Northern Norway with employees having excellent proficiency in doing architectures, design, and implementations of systems. However, the skills of our graduates are very well received also both nationally and internationally, and a significant number of graduates are employed outside of Northern Norway.

5. Sources to corroborate the impact (indicative maximum of ten references)

Sources on the operating system course:

Prof. Kai Li, Department of Computer Science, Princeton University, 35 Olden Street, Princeton, New Jersey 08540, USA, **Phone**: +1-609-258-4637, **Email**: li@cs.princeton.edu, **URL**: https://www.cs.princeton.edu/people/profile/li, **Wikipedia**: https://en.wikipedia.org/wiki/Kai_Li

Principal Software Architect Dr. Åge Kvalnes, Microsoft Development Center Norway, **Phone**: +47 480 11 113, **Email**: aagekv@outlook.com

Sources on the quality of the candidates:

CEO Dr. Bjørn Olstad, Microsoft Development Center Norway (MDCN),
Email: Bjornol@microsoft.com, **URL**: https://www.linkedin.com/in/bjorn-olstad/?originalSubdomain=no, **Wikipedia**: https://no.wikipedia.org/wiki/Bj%C3%B8rn_Olstad

(The MDCN R&D division in Tromsø has in the order of 80 employees, with a majority being graduates from UiT. Other graduates work at the MDCN headquarter in Oslo, and in the US.)

Principal Software Architect Dr. Åge Kvalnes, Microsoft Development Center Norway
Phone: +47 480 11 113, **Email**: aagekv@outlook.com

Professor Pål Halvorsen, Department of Computer Science, Oslo Metropolitan University, Norway,
Phone: +47 970 80 007, **Email**: pal.halvorsen@oslomet.no,
URL: https://www.oslomet.no/en/about/employee/palh/

Product Manager Dr. Bjørn Fjukstad, DIPS AS
Phone: +47 48 14 90 92, **Email**: bfj@dips.no, **URL**: https://fjukstad.io/

(DIPS is a Norwegian supplier of digital (journal) systems in Norway, and the company is provider of such eHealth systems to three of Norway's four regional health trusts. This includes five of the six Norwegian university hospitals. DIPS has in the order of 400 employees, with the main office in Bodø. Due to the prevalence of proper CS graduates from UiT (according to a public company statement), the company has established an R&D division in Tromsø with 75-80 employees. We refer to Dr. **Bjørn Fjukstad**, one of our PhD graduates, for more details about our education and candidates.)

University of Agder (UiA), Faculty of Engineering and Science (TekReal), case 3

Institution: University of Agder
Administrative unit: Faculty of Engineering and Science (TekReal)
Title of case study: Tsetlin Machines
Period when the underpinning research was undertaken: 2018-
Period when staff involved in the underpinning research were employed by the submitting institution: 2002-
Period when the impact occurred: 2019-

1. Summary of the impact

This case study describes the impact of a new machine learning paradigm, namely, Tsetlin machines, that was initiated by the Centre of AI Research at the Department of ICT, UiA, in 2018. The paradigm provides a fundamental shift from deep learning to logic-based machine learning, impacting the environment, society, and industry. Tsetlin machines employ finite automata to learn patterns with logical rules. The combination of finite automata and logical rules makes Tsetlin machines transparent and interpretable. Simultaneously, they become particularly suited for cutting-edge hardware solutions, enabling nano-scale intelligence, ultra-low energy consumption, energy harvesting, and unrivaled inference speed.

2. Underpinning research

Recent research has brought increasingly accurate learning algorithms and powerful computation platforms. However, the accuracy gains come with escalating computation costs, and models are getting too complicated for humans to comprehend. Mounting computation costs makes AI an asset for the few and impact the environment. Simultaneously, the obscurity of AI-driven decision-making raises ethical concerns. We are risking unfair, erroneous, and, in high-stakes domains, fatal decisions.

Tsetlin machines [Granmo, 2018] is a new research paradigm where groups of Tsetlin automata produce logical expressions in the form of conjunctive clauses (AND-rules), addressing the following key challenges:

- They are universal function approximators, like neural networks.
- They are rule-based, like decision trees.
- They are summation-based, like Naive Bayes classifier and logistic regression.
- They are hardware-near, with ultra-low energy- and memory footprint.

As such, the Tsetlin machine is a general-purpose, interpretable, and low-energy machine learning approach. In contrast to the black-box nature of deep neural networks, Tsetlin machines are inherently interpretable. They produce models based on sparse disjunctive normal form, which is comparatively easy for humans to understand. Additionally, the logical representations combined with automata-based learning make Tsetlin machines natively suitable for hardware implementation, yielding ultra-low energy footprint [Wheeldon et al., 2020]. Tsetlin machines now support various architectures, including convolution, regression [Abeyrathna et al., 2020], deterministic, weighted, autoencoder, contextual bandit [Seraj et al., 2022], relational [Saha et al., 2022], and multiple-input multiple-output architectures. Particularly within natural language understanding, the Tsetlin machine has been able to compete with deep learning approaches, employing reasoning by elimination [Yadav, et al.,

2022]. The independent nature of clause learning allows efficient GPU- based parallelization, providing almost constant-time scaling with reasonable clause amounts [Abeyrathna et al., 2021]. Several schemes enhance vanilla Tsetlin machine learning and inference, such as drop clause, and focused negative sampling. Being logic-based and driven by finite automata, Tsetlin machine learning offers global convergence properties [Zhang et al., 2022].

- Prof. Ole-Christoffer Granmo, Department of ICT, UiA (2002-)
- Prof. Lei Jiao, Department of ICT, UiA (2014-)
- Prof. Morten Goodwin, Department of ICT, UiA (2012-)
- Bimal Bhattarai, Department of ICT, UiA (2019-2023)
- Dr. Rohan Kumar Yadav, Department of ICT, UiA (2019-2022)
- Dr. Darshana Abeyrathna, Department of ICT, UiA (2018-2022)
- Rupsa Saha, Department of ICT, UiA (2020-)
- Dr. Jivitesh Sharma, Department of ICT, UiA (2017-2023)
- Adjunct Prof. Vladimir Zadorozhny, Department of ICT, University of Agder (2018-)
- Adjunct Prof. Alex Yakovlev, Department of ICT, University of Agder (2020-)
- Adjunct Prof. Rishad Shafik, Department of ICT, University of Agder (2020-)
- Dr. Christian Dallas Blakely, Department of ICT, University of Agder (2020-)

3. References to the research

[Granmo, 2018] Ole-Christoffer Granmo: The Tsetlin Machine - A Game Theoretic Bandit Driven Approach to Optimal Pattern Recognition with Propositional Logic. CoRR abs/1804.01508 (2018) https://arxiv.org/abs/1804.01508

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[Yadav et al., 2022] Rohan Kumar Yadav, Lei Jiao, Ole-Christoffer Granmo, Morten Goodwin: Robust Interpretable Text Classification against Spurious Correlations Using AND-rules with Negation. IJCAI 2022: 4439-4446 (2022) https://doi.org/10.24963/ijcai.2022/616

[Zhang et al., 2022] Xuan Zhang, Lei Jiao, Ole-Christoffer Granmo, Morten Goodwin: On the Convergence of Tsetlin Machines for the IDENTITY- and NOT Operators. IEEE Trans. Pattern Anal. Mach. Intell. 44(10): 6345-6359 (2022) https://ieeexplore.ieee.org/document/9445039

[Seraj et al., 2022] Raihan Seraj, Jivitesh Sharma, Ole-Christoffer Granmo: Tsetlin Machine for Solving Contextual Bandit Problems. NeurIPS 2022.

https://proceedings.neurips.cc/paper_files/paper/2022/hash/c2d550cf3b2e177deb2d1720fb1e2710-Abstract-Conference.html

4. Details of the impact

The Tsetlin machine paradigm has had environmental, societal, and industrial impact, as described in the following.

First of all, the Tsetlin machine paradigm has open up for logic-based machine learning in many application areas: low-power keyword spotting [Lei et al., 2021], aspect-based sentiment analysis [Yadav et al., 2021], novelty detection [Bhattarai et al., 2022], semantic relation analysis [Saha et al., 2021], text categorization [Yadav et al., 2022], game playing [Giri et al., 2022], battery-less sensing [Bakar et al., 2022b; Bakar et al., 2022a], legal document analysis [Saha and Jyhne, 2022], and recommendation systems [Borgersen et al., 2023]. In an increasing number of these benchmarks, accuracy is superior or competitive with relevant deep learning techniques. Further, they document that Tsetlin machine models are interpretable, making sense to the human user.

Environmentally, the Tsetlin machine paradigm has led to the development of battery-less energy-harvesting solutions for machine learning at Georgia Tech (US) and Nokia Bell Labs (UK) [Bakar et al., 2022b; Bakar et al., 2022a]. Further, a new class of ultra-low energy hardware chips has been developed by Newcastle University, founded on the Tsetlin machine, now offering 10 000 times less energy consumption compared to commercial neural network chips, and increases the throughput by 1 000x [Mignon, 2018; Mignon, 2022].

Societally, we have impacted the application of machine learning at Sørlandet Hospital, Sichuan University/West China Hospital, and NMBU, who respectively have found new ways to perform natural language understanding for electronic health records [Berge et al., 2019], ECG analysis [Zhang et al., 2023], and analysis of structured healthcare data [Jenul et al., 2022]. To this end, they have exploited the Tsetlin machine to achieve interpretability for doctors, and for ECG analysis and electronic health records, they reported accuracy competitive with deep learning.

Industrially/commercially, our Tsetlin machine research has provided the basis for new companies and new machine learning applications. The company Mignon has commercialized a Tsetlin machine chip that uses 10 000 times less energy than commercial neural network chips, and increases the throughput by 1000x [Mignon, 2018; Mignon 2020]. PwC Switzerland has explored the use of Tsetlin machines in various projects within finance [Blakely, 2021].

Our Tsetlin machine research has further led to multiple larger research projects that build upon the Tsetlin machine. We expect these projects to extend the impact of Tsetlin machines in the future:

- EPSRC: SONNETS – Scalability Oriented Novel Network of Event Triggered Systems. Project Code: EP/X036006/1. Co-Investigator. Read more
- EPSRC: ESTEEM – Exploiting the dynamics of self-timed machine learning hardware. Project Code: EP/X039943/1. Co-Investigator. Read more
- NFR: SecureIoTM – Ultra-low-energy IoT Intrusion Detection Systems using Logic-based Tsetlin Machines. Project code: 342167. Principal Investigator. Read more
- NFR: CaReLearner – Causal Reasoning with Logical Interpretable Learning. Project Code: 335700. Principal Investigator. Read more
- NFR: Logic-based Artificial Intelligence Everywhere – Tsetlin Machines in Hardware. Project Code: 312434. Principal Investogator. Read more
- Nokia Bell Labs: Energy-Autonomous Pervasive AI Hardware. Co-Investigator.

For broader impact, we planned an open co-creation and dissemination strategy. This includes open sharing of research: data, source code, and papers, as well as strong visibility in media, and actively engaging public and private sectors through conferences and workshops. The basic philosophy of CAIR is growth through sharing. We have chosen to share everything we publish and develop in open archives so that others can quickly benefit from the results within innovation and service development, as well as stimulate further research. We have deployed several repositories implementing our Tsetlin machine research, including https://github.com/cair/TsetlinMachine and https://github.com/cair/tmu, with several 100 visitors and downloads every week.[1] We have also shared all our key papers on arXiv and/or in open channels, and we have founded an international conference series to broaden the impact of our work, The International Symposium on the Tsetlin Machine (www.istm.no), running for the third time in 2024. For dissemination to the public, we established a presence on LinkedIn (2400+ followers, https://www.linkedin.com/company/cair-center-for-artificial-intelligence-research), Twitter (1200+ followers,), and Facebook (400+ followers), focusing on disseminating the Tsetlin machine research. The Tsetlin machine is today part of the exhibition I/O at the Norwegian Technical Museum and was the most popular object there in 2022 [Teknisk Museum, 2022].

5. Sources to corroborate the impact

[Berge et al., 2019] Geir Thore Berge, Ole-Christoffer Granmo, Tor Oddbjørn Tveit, Morten Goodwin, Lei Jiao, Bernt Viggo Matheussen: Using the Tsetlin Machine to Learn Human-Interpretable Rules for High-Accuracy Text Categorization With Medical Applications. IEEE Access 7: 115134-115146 (2019) https://ieeexplore.ieee.org/document/8798633

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[Lei, 2021] Lei, Jie, Tousif Rahman, Rishad Shafik, Adrian Wheeldon, Alex Yakovlev, Ole-Christoffer Granmo, Fahim Kawsar, and Akhil Mathur: Low-Power Audio Keyword Spotting Using Tsetlin Machines. Journal of Low Power Electronics and Applications 11, no. 2: 18 (2021) https://doi.org/10.3390/jlpea11020018

[Blakely, 2021] Christian Dallas Blakely: OrderFlowFX, an advanced realtime market flow and orderbook interactive system (2021) https://www.linkedin.com/pulse/orderflowfx-advanced-realtime-market-flow-orderbook-system-blakely/

[Mignon, 2022] Mignon – Artificial Intelligence Redefined. https://www.mignon.ai

[Bhattarai et al., 2022] Bimal Bhattarai, Ole-Christoffer Granmo, and Lei Jiao. Word-level Human Interpretable Scoring Mechanism for Novel Text Detection Using Tsetlin Machines. Applied

[1] See https://pypistats.org/packages/tmu and https://pypistats.org/packages/pytsetlinmachine for current statistics.

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[Giri et al., 2022] C. Giri, O. -C. Granmo, H. Van Hoof and C. D. Blakely: Logic-based AI for Interpretable Board Game Winner Prediction with Tsetlin Machine. International Joint Conference on Neural Networks (IJCNN), Padua, Italy, 2022, pp. 1-9 (2022) https://doi.org/10.1109/IJCNN55064.2022.9892796.

[Bakar et al., 2022a] Abu Bakar, Tousif Rahman, Rishad Shafik, Fahim Kawsar, and Alessandro Montanari: Adaptive Intelligence for Batteryless Sensors Using Software-Accelerated Tsetlin Machines. In Proceedings of the 20th ACM Conference on Embedded Networked Sensor Systems (SenSys '22). Association for Computing Machinery, New York, NY, USA, 236–249 (2022) https://doi.org/10.1145/3560905.356851

[Bakar et al., 2022b] Abu Bakar, Tousif Rahman, Alessandro Montanari, Jie Lei, Rishad Shafik, and Fahim Kawsar. 2022: Logic-based intelligence for batteryless sensors. In Proceedings of the 23rd Annual International Workshop on Mobile Computing Systems and Applications (HotMobile '22). Association for Computing Machinery, New York, NY, USA, 22–28 (2022) https://doi.org/10.1145/3508396.3512870

[Teknisk Museum, 2022] Kunstig intelligens fra UiA på teknologisk utstilling (2022) https://www.uia.no/nyheter/kunstig-intelligens-fra-uia-paa-teknologisk-utstilling

[Saha and Jyhne, 2022] R. Saha and S. Jyhne: Interpretable Text Classification in Legal Contract Documents using Tsetlin Machines, 2022 International Symposium on the Tsetlin Machine (ISTM), Grimstad, Norway, 2022, pp. 7-12 (2022) https://doi.org/10.1109/ISTM54910.2022.00011

[Jenul et al., 2022] A. Jenul et al.: Component Based Pre-filtering of Noisy Data for Improved Tsetlin Machine Modelling- International Symposium on the Tsetlin Machine (ISTM), Grimstad, Norway, 2022, pp. 57-64 (2022) https://doi.org/10.1109/ISTM54910.2022.00019

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[Zhang et al., 2023] Jinbao Zhang, Xuan Zhang, Lei Jiao, Ole-Christoffer Granmo, Yongjun Qian, Fan Pan: Interpretable Tsetlin Machine-based Premature Ventricular Contraction Identification. CoRR abs/2301.10181 (2023) https://arxiv.org/abs/2301.10181

University of Agder (UiA), Faculty of Engineering and Science (TekReal) case 2

Institution: University of Agder	
Administrative unit: Faculty of Engineering and Science (TekReal)	
Title of case study:	**Nurturing Inclusivity and Mastery: The Combined Effect of Mathematics Bridging Interventions and Accessible Learning Opportunities on Economics Students' Progression**
Period when the underpinning research was undertaken: 2018-2020	
Period when staff involved in the underpinning research were employed by the submitting institution: one member 2017 on, two members throughout the period	
Period when the impact occurred: from 2018 continuing	

1. Summary of the impact (indicative maximum 100 words)
This section should briefly state what specific impact is being described in the case study.

MERGA's audience and target arena for impact are mathematics instructors and educational institutions. We describe a research and development project that has led to improvements in economics students' performance and progression in mathematics courses at UiA and other Norwegian universities. The project has been led by a group within the "Teaching and learning mathematics in higher education team, and comprises the research of a PhD fellow (IL). If the timeframe were extended beyond 2022 we would also point to international impact.

2. Underpinning research

Nationally and internationally institutions struggle with students' performance and progression in mathematics courses for economics education. Our concern focuses on economics students' transition from school to university relating to diversity of mathematics background and missed opportunities to study the basic mathematics needed for successful transition into mathematics in economics education. The research inquired into the effectiveness of *"a new blended-learning pre-course (of prerequisite mathematics) intervention, consisting of a diagnostic test in combination with a bridging course, was implemented in 2018.*"

The "*study investigated whether participation in a bridging course, and what aspects of it, can contribute to equal opportunities and increased inclusivity in the Mathematics for Economists course, and henceforth reduce the failure rate. It adds to the meager European literature on remedial course effectiveness. Through the use of ordinary least square regression analyses, a significant positive effect of participation in the bridging course was found for the student group as a whole. Furthermore, the results indicated that participation was particularly valuable for the least mathematically prepared students***."**

The bridging course was designed and implemented by a group within MERGA. The project was set up in 2017 by MatRIC with the recruitment of a PhD fellow that combined competencies in teaching mathematics and a background in finance/economics mathematics. Supervisors were chosen who would advise from complementary perspectives of mathematics education research and mathematics instruction to students on the economics programme. Fieldwork and data generation took place in 2018, preliminary analysis of data in 2019. The development aspects of the project included innovative features, such as the use of a Computer Aided Assessment programme (NUMBAS, Newcastle University, UK) that students could use to test whether they were in command of the prerequisite knowledge needed for the mathematics for economy course. A semester long economics focused mathematics bridging course, structured so that students could join at a point matching the extent of their knowledge (this arrangement required the UiA School of business and Law to change the order of courses in the first year of their programmes). The bridging course is voluntary, and participation receives no credit.

"*Three achievement variables and four process variables were used in the analysis. The achievement measures for each student were their scores on the pre-test, post-test, and course exam. The process measures for each student were the number of workshops they attended, of training fields where they studied more than 50% of the tasks provided, of written exercises with worked solutions accessed, and of written theory documents accessed online. Ordinary-least-square regression (OLS) in several hierarchical stages with blockwise entry was found to be the most appropriate method to investigate what process variables (workshops, training, exercises, theory) seem to be of importance for students participating in the bridging course in terms of their performance on the post-test and most importantly on the Mathematics for Economists course exam*."
Dates carried out: 2018-2020.
Quotations from: Landgärds, I. M. (2021). The Impact of a Mathematics Bridging Intervention on the Inclusivity of a University Economics Programme. *Paper presented at the MNT conference 2021*. DOI: https://doi.org/10.5324/njsteme.v5i1.3904
Available at: https://www.ntnu.no/ojs/index.php/njse/article/view/3904

- Ida Maria Landgärds-Tarvoll (PhD fellow – MERGA).
- Prof. Kenneth Ruthven (Adjunct professor of mathematics education - MERGA)
- Prof. Rolf Nossum (Professor of mathematics, co-opted into MERGA due to his knowledge and experience of the context).

3. References to the research

Author: Landgärds, I. M.
Title: The Impact of a Mathematics Bridging Intervention on the Inclusivity of a University Economics Programme.
Year of publication: 2021.
Type of output: Paper presented at the MNT (STEM) conference 2021. And subsequently published in the peer reviewed journal Nordic Journal of STEM Education.
DOI: https://doi.org/10.5324/njsteme.v5i1.3904
Available at: https://www.ntnu.no/ojs/index.php/njse/article/view/3904

Author: Landgärds, I.
Title: Providing economics students opportunities to learn basic mathematics
Year of publication: 2019
Type of output: Paper presented at the MNT (STEM) conference 2019 (peer reviewed).
DOI: https://doi.org/10.5324/njsteme.v3i1.2992
Available at: https://www.ntnu.no/ojs/index.php/njse/article/view/2992/2918 (paper at pages 185-189)

Author: Landgärds, I.
Title: Mathematics Teaching for Economics Students, But How?
Year of publication: 2018
Type of output: Poster presentation at the Second conference of the International Network for Didactic Research in University Mathematics
Available at: https://hal.science/INDRUM2018/public/Indrum2018Proceedings.pdf (pages 187-188).
ISSN: 2496-1027 (online)

3. Details of the impact

Introduction

Interventions intended to address students' poor performance and progression can elicit skepticism on from mathematics instructors who argue: "the intervention has reduced the demand and cognitive challenge; the improved results are achieved by lowering standards." This project addresses often justified skepticism through methodology that generates and collects valid data and applies reliable and meaningful analytic approaches that point to the trustworthiness of claims made about the intervention.

The intervention: a mathematics bridging course extending over one semester, incorporating blended learning approaches, weekly lectures and problem-solving sessions, and a variety of online learning resources.

The intervention is substantial in design, structure and content.

This narrative focuses on the research that underpins the impact (locally and nationally).

Data generated

Achievement variables:

- An online diagnostic test (pre-test) at the beginning of their first semester, prior to the bridging course intervention.
- The same test (with items given new numeric values) was then administered at the start of the second semester (post-test), i.e., following the intervention. ("*postscore*")
- Mathematics for Economics course examination, at the end of the second semester. ("*examscore"*)

Process variables (composite variable "*participation*"):

- Students' participation in workshops (number attended).
- Students' use of training fields (online quizzes with help-options where the student can pause and learn more about how to solve such exercises through videos and written explanations before continuing with the exercise) (number in which more than 50% was completed).
- Students' use of written exercises with fully worked solutions (number of).
- Students' use of written theory documents (number of).

Analysis

"*Ordinary-least-square regression (OLS) in several hierarchical stages with blockwise entry was found to be the most appropriate method to investigate what process variables (workshops, training, exercises, theory) seem to be of importance for students participating in the bridging course in terms of their performance on the post-test and most importantly on the Mathematics for Economists course exam*." Landgärds 2021).

Findings

The analysis reveals ''*The existence of a process effect was established by forming the composite participation variable which positively and significantly predicted both postscore and examscore*'' (Landgärds 2021).

Participation in the bridging course was found to be beneficial for the students beginning from a high school course with reduced mathematics content (i.e., the students had no prior experience of calculus and limited experience of pre-calculus mathematics); this was a core segment of the target group. Greater participation in the bridging course was related to stronger performance in the examination.

Overall performance in the Mathematics for Economics examination at UiA improved with failure rates dropping from around 30% (mean, range 19%-48%) over 7 years prior to the introduction of the bridging course to about 11% (mean, range 1,6%-16%) over 5 years following its introduction. UiA's failure rates for first year students are now only bettered by students at Norway's two leading business schools that have a high attainment threshold for admission.

The rigorous methodology and analysis that points to the benefits of the bridging course, and the critical watchfulness of academics in UiA's School of Business and Law, and external examiners addresses any suspicion that standards may have been lowered.

Dissemination

The research took place in the context of close collaboration between the Department of Mathematical Sciences and UiA's School of Business and Law. Thus, the first rung of the impact ladder occurred as MatRIC extended its influence beyond its home faculty. The success of the intervention underpinned by rigorous research was first presented nationally at the 2018 annual meeting of the Economics and Administration Subject Group of the Norwegian Association of Higher Education Institutions (https://www.uhr.no/en/strategic-units/), and subsequently in 2021 in a podcast produced by the Norwegian Agency for Quality Assurance in Education (https://www.nokut.no/en/about-nokut/)[ii]. The research and findings were presented at national STEM conferences in 2019 and 2021, and internationally at the International Network for Didactics Research in Mathematics (INDRUM) in 2018. The convincing findings, grounded in a solid research design and high quality of analysis has held the attention of instructors and programme leaders who also face the near ubiquitous issues of students' poor performance and progression in mathematics for economics courses. There has also been some interest in the developments from teacher education programmes (e.g. at the University of Stavanger) that also struggle with students' performance and progression in mathematics.

Direct beneficiaries

- Students joining the economics programme
- UiA's School of Business and Law – overcoming the struggle with student progression contributed to the 'School' achieving AACSB accreditation.[iii]
- University of Agder, financial benefit accruing from improved student completion rates and reputational benefit.
- Other Business Schools (and their students) that have been convinced by the research and implemented a similar intervention. E.g., Østfold University College.
- Teacher Education Programmes (and their students). E.g., University of Stavanger.

5. Sources to corroborate the impact

UiA School of Business and Law: Kristin wallevik (Dean, kristin.wallevik@uia.no) and Kerttu Kettunen (programme leader, kerttu.kettunen@uia.no**)**

UHR-Economics and Administration annual meeting 2018: Stine Rye Bårdsen (stine.r.bardsen@uia.no)

Norwegian Agency for Quality Assurance in Education: PeterBrandstrup (Peter.Brandstrup@nokut.no)
Østfold University College: Erlend Sand Aas **(**erlend.s.aas@hiof.no).
University of Stavanger: Morten Ugelid Søyland (morten.s.soyland@uis.no)

[i] Podcast is in Norwegian, available at https://soundcloud.com/nokutpodden/den-om-forkurs?utm_source=clipboard&utm_campaign=wtshare&utm_medium=widget&utm_content=https%253A%252F%252Fsoundcloud.com%252Fnokutpodden%252Fden-om-forkurs

[ii] Podcast is in Norwegian, available at https://soundcloud.com/nokutpodden/den-om-forkurs?utm_source=clipboard&utm_campaign=wtshare&utm_medium=widget&utm_content=https%253A%252F%252Fsoundcloud.com%252Fnokutpodden%252Fden-om-forkurs

[iii] See https://www.uia.no/en/about-uia/faculties/school-of-business-and-law/international-accreditation

University of Agder (UiA), Faculty of Engineering and Science (TEKREAL), case 1

Institution: University of Agder
Administrative unit: Faculty of Engineering and Science (TekReal)
Title of case study: SFI Offshore Mechatronics
Period when the underpinning research was undertaken: 2015-2023
Period when staff involved in the underpinning research were employed by the submitting institution: 2015-2023 – 29 all together (Phds, post-docs and scientific staff)
Period when the impact occurred: from 2015-2023 (and continuing)

Based on Final Report – 2015-2023 | (mechatronics.no)

1. Summary of the impact

The SFI has successfully served as a platform for comprehensive R&I for the offshore mechatronics area. The success of the centre is based on the strong integration of collaboration between the research environment of the universities and research institute, and the industrial partners This environment includes not only research and innovations, but also education and student projects. The research partners achieved very good alignment with the user partners within their expectations and boundary conditions as partly competing companies. This gave basis for a relevant environment and results that contribute to innovative solutions and commercial products.

	2015	2016	2017		2018	2019	2020	2021	2022	2023	Total
Scientific publications (peer reviewed)		16	29		33	40	44	19	13	10	202
Dissemination measures for users	12	5	6		23	19	14	17	11	4	111
Dissemination measures for the general public	1	15	15		2	5	1	3	2	7	51
PhD degrees completed						1	7	7	4	2	21
Master degrees		20	38		77	16	23	18	26	8	226
Number of new/improved methods/models/prototypes finalised		1			4	2	1	3	1		12
Number of new/improved products/processes/services finalised			1						1	2	4
Patents registered						1					1
New business activity		1	1		1	1	1	0	2	0	7

2. Underpinning research

The industry has built internal capability and skills for research-based developments. They have improved the knowledge base for more advanced mechatronics control and safety and enhanced their ambitions on R&D-based innovations. Spin-off projects for more advanced and complex technologies was initiated and more advanced products have been brought to market. New business models are now also being considered.

The academic partners in the centre not only aspired to collaboration with the industrial partners, but also co-creation, but this was mostly too difficult due to the competitive characteristics of the industrial partners. The research thus aimed for TRL 2-5, and the results have been offered to the user partners to harvest appropriate results, enabling them to innovate and develop their new products.

In the centre we have managed to unify high industrial relevance with high academic ambitions. We are proud that 23% of the journal articles from the centre have been published in Level 2 journals. The total publication rate was and is still as expected.

The reports from the Ph.D. evaluation committees during defences have given us valuable feedback demonstrating that the quality of the research has been relevant and on high levels. The centre provided a large number of Ph.D. and associated M.Sc. candidates that matched the need of the industry for recruitment. This is one of the best ways to provide competence. The mutual and collective collaboration between the research partners NTNU, AAU, NORCE and UiA have been very good and

fruitful.

The consortium managed to deal with unforeseen issues in a coherent and cooperative manner with the aim of minimising impact and negative consequences for centre activities. In particular, the centre industry partners faced a significant financial downturn in the middle of the last decade, but the centre was largely shielded regarding resources and financial contributions.

On the other hand, the rise of artificial intelligence was exploited as a new opportunity for the centre. Apart from the work package on Data Analytics & Big Data, the original application did not put much emphasis on artificial intelligence (AI) or machine learning techniques or tools (ML). At that time, AI and ML had not yet become mainstream.

Today, we know that AI and ML in the last 8 years have seen unprecedented growth and adoption. This development influenced the research work at the centre. The use of artificial intelligence and machine learning played an important role, became highly integrated as analytical methods and algorithm design, and had a high impact on research results.

It was recognised underway that the innovation potential of research results had to be addressed, and an innovation officer was thus hired to manage and strengthen these efforts. We still see that there is a need to strengthen the culture of 'disclosure of invention' within university environments. However, we have experienced that the volume of significant innovative work was done by the industrial partners.

The centre also aimed to promote spin-off research projects. Estimates have shown that the grants to spin-off projects by far exceed the total cost of the centre. The research partner NORCE has been invited to Horizon Europe projects on condition based control on transport systems based on capabilities developed at the centre. It is more challenging to approach Horizon Europe with key competence in offshore mechanics aimed at oil and gas industries, as this is not a priority area of interest for the EU. But now both research and industrial partners are approaching new arenas such as offshore wind, wave energy, ocean farming, deep-sea mineral mining, and autonomous marine operations. This includes also building new partnerships for new RCN funded projects and centres.

In December 2022, a review of the strategic options developed in the early phase was made and to what extent the recommendations from that process had been followed and to what extent they were still valid. The review concluded that all strategic options were followed in terms of work package activities and results, as well as spin-off projects. The review also concluded that all strategic options are still very much valid within a broad range of offshore operations.
As the centre is vital, we aim to continue the collaboration and extend the partner base to pursue new opportunities as the Centre for Offshore Mechatronics.
Final Report – 2015-2023 | (mechatronics.no)

3. **References to the research**

Based on overview from SFI Offshore Mechatronics Final Report 2015-2023

Year	Award	Details
2023	Best Student Paper Award	The paper "Embedding Clustering using Lightweight Contrastive Learning For Cross-Modal Classification" by José Amendola, Linga Reddy Cenkaramaddi, A. Jha was awarded with Best Student Paper Award at the The 8th International Conference on Computer and Communication Systems (ICCCS 2023).

2022	Best Paper Award	The paper “Joint Learning of Topology and Invertible Nonlinearities from Multiple Time Series” by Kevin Roy; Luis Miguel Lopez-Ramos; Baltasar Beferull-Lozano was awarded with Best Paper Award at the IEEE International Seminar on Machine Learning, Optimization, and Data Science (ISMODE 2022)
2021	Runner-up Best Journal Paper Award	The paper “Priority Enabled Grant-Free Access With Dynamic Slot Allocation for Heterogeneous mMTC Traffic in 5G NR Networks” by Thilina N. Weerasinghe; Vicente Casares-Giner; Indika A. M. Balapuwaduge; Frank Y. Li was awarded runner-up Best Journal Paper IEEE ComSoc – CSIM (Communications Systems Integration and Modeling (CSIM) Technical Committee) Journal 2021 Edition
2020	Best Presentation Award	The presentation by Dipendra Subedi based on the paper "Modeling and Analysis of Flexible Bodies Using Lumped Parameter Method” by Dipendra Subedi; Ilya Tyapin; Geir Hovland was awarded with Best Presentation Award in Session 2: System Control and Management Engineering at the 2020 IEEE 11th International Conference on Mechanical and Intelligent Manufacturing Technologies
2018	Best Application Paper Award	The paper “Visual Marker Guided Point Cloud Registration in a Large Multi-Sensor Industrial Robot Cell” by Erind Ujkani, Joacim Dybedal, Atle Aalerud, Knut Berg Kaldestad and Geir Hovland received the Best Applications Paper Award at the IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications (MESA).
2016	Best Session Presentation Award	The presentation by Sondre Sanden Tørdal based on the paper "Testing of Wireless Sensor Performance in Vesselto-Vessel Motion Compensation” by Sondre Sanden Tordal; Per-Ove Løvsland; Geir Hovland was awarded with best session presentation award at the 42nd Annual Conference of the IEEE Industrial Society (IEEE-IECON 2016).
2015	Best Presentation Award	The presentation by industrial PhD candidate Witold Pawlus based on the paper “Drivetrain Design Optimization for Electrically Actuated Systems via Mixed Integer Programing” by W. Pawlus, D. Frick, M. Morari, G. Hovland and M. Choux was awarded with Best Presentation award at the IECON 2015 conference in the session “TS-140 Electrical Drive Applications”.

4. Details of the impact

Introduction

The centre has produced 202 peer-reviewed publications. To date 21 PhDs have been completed, 11 remain and are expected to complete by 2024. Furthermore, 226 master’s students have had related main assignments linked to the centre’s theme, two of whom have gone on to establish their own companies. Important results have been obtained.

- Motion compensation control algorithms for antisway
- Control models for wave compensation for ship-to-ship cargo handling.
- Modelling and cosimulation of ship movements and motion-compensated cranes
- Modelling of nonlinear dynamic systems
- Prediction of failure events in complex production facilities with “hidden information”
- On-the-go smooth decompression of PI industrial data with quality constraints
- Control models for digital hydraulics

- Precision control and damping of long-armed robots
- Acoustic methods for fault detection in hydraulic systems
- Three-dimensional machine vision with LIDAR scanning (patented)
- Condition monitoring and remaining life management based on machine learning of
- Fibre ropes with optical-thermal monitoring
- Steel ropes with acoustic monitoring
- Large slow-moving rotating bearings with acoustic monitoring
- Gear systems with acoustic monitoring
- Initiation and life of fatigue of welds with multiaxial loading

INNOVATION DEVELOPMENTS

To link the research results with the innovation potential, a separate innovation manager was eventually employed, who developed a separate mapping system for innovation potential from the research results at the academic partners. In addition, the industry cluster that ran the foresight activities was engaged in active dialogue with the user partners. It became clear early on that the industrial partners themselves had to develop their own organisations to be able to interact with the R&D environments for useful dialogue and utilisation of the potentials. Similarly, academic participants had to learn to respect the framework under which competing industrial partners are subject. This drove the research towards a somewhat lower but still very satisfactory level of technology readiness. Unfortunately, the collaboration faced some difficult conditions during the years of the Covid19 pandemic.

It must be emphasised that the major advanced innovations have been developed by the industrial partners, based on results and candidates from the centre and the associated environments. Here we can mention PileGripper from MacGregor, autonomous mooring of unmanned ships, wave compensation of very large crane lifting systems, machine vision system for movement control and safety, new condition monitoring solutions, etc.

EXTENDED AREAS OF USE

In addition to still being able to contribute to more efficient and safe oil and gas operations at sea with lower energy consumption, the following other very relevant industrial sectors have or may start to make use of our results.

- Renewable energy, in particular
- Installation, operation, and maintenance of wind power, land and sea
- Solar power land and sea
- Wave power
- Hydropower plant
- Large-scale automation of production and assembly (of marine structures)
- Unmanned land and sea transport
- Aquaculture
- Ports / harbours
- Mineral collection and extraction on the seabed
- Building and construction, infrastructure
- Process industry
- Defense equipment and facilities

INTERNATIONAL NETWORK

The centre included collaboration with Aalborg University (AAU), which also partially took over task responsibility for the activities of hydraulic actuators. There has been a very strong interaction between AAU and UiA along the way with mutual PhD guidance and courses. At RWTH Aachen, two

research fellows have contributed to the project with very interesting research topics for machine system analyses and predictive control.
We had two active foreign user partners with us for large parts of the project period who found the project very useful and put up a strong team in our events. However, these withdrew towards the end as their main areas of interest were finished earlier.

KNOWLEDGE EXPANSION

The SFI project has carried out research in areas such as hydraulics, robotics, automation and condition monitoring of machinery. NOV was involved in many of these, including projects on motion compensation, robotics and automation. They see that the project is adding value to the industry in the region. Peder Sletfjerding (Sletfjerding coordinated NOV's involvement in the SFI project) believes that NOV has benefitted substantially from the SFI collaboration. In addition to developing the new crane, the company has also initiated several development projects, and the employees involved have enhanced their skills and knowledge in various areas. "We've gained new expertise, especially in camera technology and simulation. There is a lot going on in such collaborative projects, both formally and informally, between us and the students involved, and between us, UiA and other collaboration partners," he says.

Dissemination

The regular reference group meetings have been the main communication and dissemination channel. The annual conference has been the main common event for dissemination across the project. The conference took place every year of the project except in 2020 and 2021 due to COVID-19. The conference has attracted between 50 and 80 participants from industry and academic partners. The final annual conference in 2023 was also partly open to external participants.

For external communication, the website sfi.mechatronics.com has been used. The centre had accounts and presence in social media and professional networks such as LinkedIn, but the activity was limited. The news stories on the website were periodically communicated via a newsletter with more than 300 recipients.

The centre has co-hosted several public events such as Science Meets Industry, Ocean Technologies workshop and events during Arendalsuka. During the Covid-19 pandemic webinars were actively used to disseminate results from the centre. The webinars were also used to have invited external guests presenting topics of interest to both academic and industry partners.

In the project period more than 200 papers have been published in journals and at conferences. Less than 15 percent of the papers are published in non open-access journals. Github was used as an open source repository and Dataverse.no was used as a repository for datasets. This is in line with the FAIR principles to improve the Findability, Accessibility, Interoperability, and Reuse of digital assets.

5. Sources to corroborate the impact

UiA Centre Management:
Geir Grasmo
geir.grasmo@uia.no

Steering board, chairs:
2021-2023: Tom Fidjeland
tom@gcenode.no

USN-EIK 1

Institution: University of South-Eastern Norway (USN)
Administrative unit: Department of Electrical Engineering, IT and Cybernetics (EIK)
Title of case study: Semikidd (Sensors and models for improved kick/loss detection in drilling)
Period when the underpinning research was undertaken: 2016-2020
Period when staff involved in the underpinning research were employed by the submitting institution: 2016-2021
Period when the impact occurred: 2016-2021

1. Summary of the impact (indicative maximum 100 words)

This section should briefly state what specific impact is being described in the case study.

Four PhD candidates and more than 90 MSc and BSc students with thesis and project work have participated in this project. The industry got knowledge about status and development of models and algorithms for flow of fluids in open channels, and the need to improve measurement quality. Distributed flow is relevant for oil/gas production, hydropower production, and in many other fields. This includes the use of machine learning in many of the fields. The project made USN better equipped to contribute to industrial challenges.

DigiWell, a NFR project started in 2020, is a continuation of this project with the same industrial partners.

2. Underpinning research (indicative maximum 500 words)

This section should outline the key research insights or findings that underpinned the impact, and provide details of what research was undertaken, when, and by whom. This research may be a body of work produced over several years or may be the output(s) of a particular project. References to specific research outputs that embody the research described in this section, and evidence of its quality, should be provided in the next section. Details of the following should be provided in this section:

- The nature of the research insights or findings which relate to the impact claimed in the case study.
- An outline of what the underpinning research produced by the submitted unit was (this may relate to one or more research outputs, projects, or programmes).
- Dates of when it was carried out.
- Names of the key researchers and what positions they held at the administrative unit at the time of the research (where researchers joined or left the administrative unit during this time, these dates must also be stated).
- Any relevant key contextual information about this area of research.

The *primary objective* was to enable cost-effective and automatic kick/loss detection by developing new knowledge on model-based estimation and utilization of new sensor technology for drilling operations.

Four research tasks (RTx) were performed with the following secondary objectives:

RT1: Modelling of return channel flow under transient conditions involved PhD candidate Prasanna Welahettige and main supervisor professor Knut Vaagsaether together with professor Bernt Lie and the Computational Fluid Dynamics team of Telemark Process Safety, Combustion and Explosion Laboratory (TPSCEL) research group (RG) at USN. The work

included cooperation with industrial PhD candidate Christian Berg at Kelda AS. The research insights were a 1) 3D CFD model implemented and tested against experimental data with a Venturi rig at USN, and 2) a 1D modified model for a non-prismatic cross section to capture the wall-reflection pressure-force effect in irregular geometry with resulting oblique jump at the Venturi throat.

RT2: Combined estimation of return flow rate and active pit level involved PhD candidate Asanthi Jinasena and main supervisor Roshan Sharma in Applied Modeling and Control (AMOC) RG at USN, together with co-supervisor from Kelda AS. The research insights were 1) a model of the return flow with active pit developed in an MSc thesis with the PhD candidate, and 2) PhD candidate developed a low-order model of the Venturi rig with a fit-for-purpose non-Newtonian friction term for flow estimation with level sensors. On-line adaptation of rheological parameters allowed for an accuracy in the flow estimate of the order of 1.5% (RMSE).

RT3: Automatic kick/loss detection utilizing new sensors and model-based fingerprinting involved PhD candidate Haavard Holta and the group of Professor Ole Morten Aamo at NTNU. The research insights were 1) the development of a distributed model of flow/shock wave propagation from the well to the topside and compared to an industry-standard, low-order Kaasa model, and 2) an advanced, adaptive parameter observer which promises significant improvement over current technology with reference to early detection of well kick/loss based on combined sensor signals from the top-side (e.g., Venturi rig estimates) and the well bore. The new algorithms were tested on industrial data from Equinor ASA.

RT4: Estimation of flow rate and fluid properties using multi sensor data fusion involved PhD candidate Morten Hansen Jondahl with supervisors Håkon Viumdal and Saba Mylvaganam in AMOC RG at USN, together with a group at research Institute NORCE in Kristiansand. This work also included some co-operation with PhD candidate Khim Chhantyal from another project. The research insight were 1) data driven static and dynamic models (neural networks, etc.) were developed and trained based on Coriolis mass flow sensor data and a number of different regressor sensor data like ultrasound, various radar types, ultrasonic doppler, density sensor, pressure sensor and temperature sensor, and 2) several different smart sensors were developed (Newtonian and non-Newtonian fluids in Venturi rig; work during internship), and all of them gave a better result than the industry standard set by NORSOK of 5 % accuracy of measured value.

3. References to the research (indicative maximum of six references)

This section should provide references to key outputs from the research described in the previous section, and evidence about the quality of the research. All forms of output cited as underpinning research will be considered equitably, with no distinction being made between the types of output referenced. Include the following details for each cited output:

- Author(s)
- Title
- Year of publication
- Type of output and other relevant details required to identify the output (for example, DOI, journal title and issue)
- Details to enable the panel to gain access to the output, if required (for example, a DOI or URL)

All outputs cited in this section must be capable of being made available to panels. If they are not available in the public domain, the administrative unit must be able to provide them if requested by RCN or the evaluation secretariate.

1. Welahettige P, Berg C, Lundberg J, Lie B, Vaagseather K (2019). «Computational fluid dynamics study of the effects of drill cuttings on the open channel flow". International Journal of Chemical Engineering. doi.org/10.1155/2019/6309261
2. Welahettige, P., Lie, B., & Vaagsaether, K. (2018). «A solution method for 1D shallow water equations using FLIC scheme for open Venturi channels". The Journal of Computational Multiphase Flows, 10(4), 228-238. doi.org/10.1177/1757482X18791895
3. Jinasena, A., Kaasa, G.-O., and Sharma, R. (2017). "Use of Orthogonal Collocation Method for a Dynamic Model of the Flow in a Prismatic Open Channel: For Estimation Purposes". In Proceedings of the 58th Conference on Simulation and Modelling (SIMS 58), pages 90–96, Reykjavik, Iceland. Linköping University Electronic Press. doi.org/10.3384/ecp1713890
4. Chhantyal, K., Jondahl, M.H., Viumdal, H., Mylvaganam, S. (2018). «Upstream Ultrasonic Level Based Soft Sensing of Volumetric Flow of Non-Newtonian Fluids in Open Venturi Channels». IEEE SENSORS JOURNAL 18 (12), 5002-5013
5. Jondahl, M.H., Viumdal, H. (2018). "Developing ultrasonic soft sensors to measure rheological properties of non-Newtonian drilling fluids". tm-Technisches Messen 86 (12), 744-757
6. Jinasena, A., et all. (2020). "Model based early kick/loss detection and attenuation with topside sensing in managed pressure drilling". In Proceedings of the 61st Conference on Simulation and Modelling (SIMS 61), Linköping University Electronic Press. doi.org/10.3384/ecp20176236

4. Details of the impact (indicative maximum 750 words)

This section should provide a narrative, with supporting evidence, to explain:

- How the research underpinned (made a distinct and material contribution to) the impact
- The nature and extent of the impact

The following should be provided:

- A clear explanation of the process or means through which the research led to, underpinned or made a contribution to the impact (for example, how it was disseminated, how it came to influence users or beneficiaries, or how it came to be exploited, taken up or applied).
- Where the submitted administrative unit's research was part of a wider body of research that contributed to the impact (for example, where there has been research collaboration with other institutions), the case study should specify the particular contribution of the submitted administrative unit's research and acknowledge other key research contributions.
- Details of the beneficiaries – who or what community, constituency or organisation has benefitted, been affected or impacted on.
- Details of the nature of the impact – how they have benefitted, been affected or impacted on.
- Evidence or indicators of the extent of the impact described, as appropriate to the case being made.
- Dates of when these impacts occurred.

The project consisted of four research tasks (RT), (RT1 to RT4), one PhD candidate for each RT. These four PhD students were recruited in the project, three in 2016, and one in 2017. All four defended their theses on time:

1. Prasanna Welahettige worked on RT1 and defended his PhD 26-SEP-2019 at USN, including three months internship at partner Equinor ASA Porsgrunn.
2. Asanthi Jinasena worked on RT2 and defended her PhD 8-OCT-2019 at USN, including three months internship at partner Kelda AS.

3. Haavard Holta worked on RT3 and defended his PhD 27-AUG-2020 at NTNU, including three months internship at partner Equinor ASA Trondheim.
4. Morten Hansen Jondahl worked on RT4 and defended his PhD 11-MAY-2020 at USN, including three months internship at partner Equinor ASA Porsgrunn.

In Research Task #1 (RT1) a 3D CFD model was implemented and tested (Newtonian, non-Newtonian) against experimental data (ultrasonic level sensors at several locations, Coriolis mass flow meter, rheometer, density meter) in a Venturi rig at USN. A 1D modified model for a non-prismatic cross section was developed, to capture the wall-reflection pressure-force effect in irregular geometry with resulting oblique jump at the Venturi throat. Non-Newtonian behavior was captured with a mix of internal and external friction slope. Normal amounts of drill cuttings in the fluid were found to have relatively little effect. The consequences of a platform exposed to ocean waves was briefly studied.

In research task # 2 (RT 2) a model of the return flow with active pit was developed in an MSc thesis together with the PhD candidate, who then developed a low-order model of the Venturi rig with a fit-for-purpose non-Newtonian friction term for flow estimation with 2-3 level sensors. On-line adaptation of rheological parameters allowed for an accuracy in the flow estimate of in the order of 1.5% (RMSE).

In research task #3 (RT3) a distributed model of flow/shock wave propagation from the well to the top-side was developed and compared to an industry-standard, low-order Kaasa model. Next, an advanced, adaptive parameter observer was developed which promises significant improvement over current technology wrt. early detection of well kick/loss based on combined sensor signals from the top-side (e.g., Venturi rig estimates) and the well bore. Promising algorithms for kick/loss detection were developed and tested through simulation. The new algorithms were tested on industrial data from Equinor ASA.
In Research task #4 (RT4) data driven static and dynamic models (neural networks, etc.) were trained based on Coriolis mass flow sensor data and several different regressor sensor data (1. level sensors: ultrasound, various radar types; 2. flow sensors: ultrasonic doppler, flow paddle, etc.; 3. immersion ultrasound sensors for rheology; 4. density sensor; 5. pressure sensor; 6. temperature sensor). Several different smart sensors were developed (Newtonian and non-Newtonian fluids in Venturi rig; work during internship), and all of them gave a better result than the industry standard set by NORSOK of 5 % accuracy of measured value. Some experimental work was done with partners Equinor and NORCE.

With partner Equinor, an experimental Venturi rig was built at USN, and used to test Venturi flow models and algorithms. Specifically, for RT1, the new 1D model was compared to both a 3D CFD simulation and experimental data from the Venturi rig. In RT2, the simplified model was compared to both the 1D model from RT1, and experimental data from the Venturi rig. The adaptive observer gave flow estimate accuracy of ca. 1.5%. For RT3, the algorithms were tested on data from Equinor ASA. Although the algorithm seems very promising, the available data were somewhat lacking in detail level, and more work needs to be done. For RT4, machine learning/smart sensors were based on experimental data from the Venturi rig, indicating an accuracy in flow rate estimates of better than 5%.

Fifteen MSc theses and two MSc projects related to Semi-kidd have been carried out. In two MSc courses a total of 40-45 students have carried large course, while some 30 BSc students have done experimental work on instrumentation related to the project.

Key acquired knowledge relates to numeric methods for hyperbolic 1D PDEs, applied machine learning for smart sensors, applied state and parameter estimation for ODEs and PDEs. This

knowledge will be included in MSc and PhD level courses at USN with examples from drilling. The results have been disseminated in 20 papers in international journals (level 1 and 2), 19 papers at international conferences with peer review, 5 various other publications. The accumulated general knowledge has already helped qualify USN for other industrial projects.

5. Sources to corroborate the impact (indicative maximum of ten references)

1. Semi-kidd (2016-2021), NFR project report, NFR project 255348.
2. Welahettige, P. (2019), Transient drilling fluid flow in Venturi channels: comparing 3D and 1D models to experimental data, PhD thesis, 204 pages, ISBN: 9788272065361, part of NFR project 255348.
3. Jinasena, A. (2019), Models and Estimators for Flow of Topside Drilling Fluid, PhD thesis, 178 pages, ISBN: 9788272065293, part of NFR project 255348.
4. Holta, H. (2020), Kick & Loss Detection and Estimation using Distributed Models, PhD thesis, 194 pages, part of NFR project 255348.
5. Jondahl, M. H. (2020), Data Driven Models for Estimation of Drilling Fluid Rheological Properties and Flow Rate, PhD thesis, 117 pages, ISBN: 978-82-7206-551-4, part of NFR project 255348.
6. DigiWell (2020-2024): oil/gas production modeling, control, and optimization – ongoing NFR project.

USN-EIK 2

Institution: University of South-Eastern Norway (USN)
Administrative unit: Department of Electrical Engineering, IT and Cybernetics (EIK)
Title of case study: Enhanced utilization of the Norwegian power system
Period when the underpinning research was undertaken: 2016-2024
Period when staff involved in the underpinning research were employed by the submitting institution: 2016-2021
Period when the impact occurred: 2016-2021

1. Summary of the impact (indicative maximum 100 words)

This section should briefly state what specific impact is being described in the case study.

One important outcome of the research in the department is the development of a new methodology and technical solution for a system optimization between Norwegian hydropower plants and the electric grid side. This work is strengthening the national power system operational security of supply and power transfer capability, while reducing investment costs and transmission losses. Further, it also optimizes the interplay between the power producer and grid owner(s). This development of new system technology pushes forward the need to outline and realize new sector regulation and framework conditions for the Norwegian Water Resources and Energy Directorate (NVE) achieved through "Guide to the Delivery Quality Regulations", and Statnett through "National Guide for Functional Requirements in the Power System". Implementation of the technology will also ensure a resilient and sustainable grid in the energy transition by reducing greenhouse gas emissions, and thereby, help reach the Paris agreement climate goals.

2. Underpinning research (indicative maximum 500 words)

This section should outline the key research insights or findings that underpinned the impact, and provide details of what research was undertaken, when, and by whom. This research may be a body of work produced over several years or may be the output(s) of a particular project. References to specific research outputs that embody the research described in this section, and evidence of its quality, should be provided in the next section. Details of the following should be provided in this section:

- The nature of the research insights or findings which relate to the impact claimed in the case study.
- An outline of what the underpinning research produced by the submitted unit was (this may relate to one or more research outputs, projects, or programmes).
- Dates of when it was carried out.
- Names of the key researchers and what positions they held at the administrative unit at the time of the research (where researchers joined or left the administrative unit during this time, these dates must also be stated).
- Any relevant key contextual information about this area of research.

Between 2016 and 2024, NTNU led a national NFR-funded initiative (FME-HydroCen) to advance hydroelectric power, with **USN as a research partner**. From start of 2019, USN researcher associate professor Thomas Øyvang started to develop a new project based on USN results within the FME-HydroCen and his PhD work from 2014 to 2018. After over 1.5 years of development of the project idea and application (January 2019 to June 2020), in close collaboration with regional companies (Skagerak Energi and Lede) and national industry (Statnett and Statkraft) and policy makers (NVE), the project titled "System optimization

between power producer and grid owners for more efficient system services (SysOpt)" was born and funded by the Research Council of Norway in late 2020 (#319945). This project became one of the first collaborative project that gathers the whole value chain of stakeholders operating and maintaining the Norwegian power system.

The primary focus has been to develop advanced models and algorithms for optimizing the utilization of hydropower within the Nordic Grid, with the aim of effecting positive change or benefit to the public economy, society, policy, and the environment. A resilient and efficient power system is one of the core infrastructures affecting everyday life. The models developed at USN enhance the short-term power capabilities of hydropower plants, contributing to novel system services for the grid. The control algorithms play a crucial role in coordinating system-level control, leading to a reduction of power losses within the electric grid. Transmission losses, manifested as the dissipation of electrical energy as heat during transportation over distances, contribute to the overall costs included in the grid tariff paid by electricity consumers.

The current state of hydropower plants relies on low-level basic setpoint controllers, primarily focusing on power-frequency controllers while overlooking the automatic voltage controller (AVR) (*Øyvang et.al*). USN's EIK unit address this gap by optimizing the interface between power producers and grid owners, emphasizing reactive power exchange and voltage support control. Ongoing projects focus on hydropower flexibility, active power control, and turbine dynamics. Simulations carried out by our team indicate increasing transmission grid losses in the Nordic grid e.g., *S. Monshizadeh et. al*, emphasizing the significance of reducing power loss through coordinated system services. However, more knowledge is needed on utilizing optimal power flow software, optimizing reactive power in distribution networks, and developing emergency control schemes for hydropower plants. The lack of coordinated optimization in voltage control systems and the absence of developed technology and service solutions pose challenges that require exploration of new incentives through market mechanisms for generating capacity participation. The research focus on the interaction between advanced control systems, operational information systems, and communication for efficient system support and enhanced services coordination. Understanding operational costs and incentives for coordinated reactive power exchange is crucial for the future of hydropower and the broader power system.

Furthermore, the acquired knowledge has significant academic effects, providing open access results that contribute to shaping the future of education.

The total research activities at USN within the thematic area of the FME centre have included 4 PhD thesis with an additional 6 PhDs from spin-off projects in the RG Electrical Power Systems.

3. References to the research (indicative maximum of six references)

This section should provide references to key outputs from the research described in the previous section, and evidence about the quality of the research. All forms of output cited as underpinning research will be considered equitably, with no distinction being made between the types of output referenced. Include the following details for each cited output:

- Author(s)
- Title
- Year of publication

- Type of output and other relevant details required to identify the output (for example, DOI, journal title and issue)
- Details to enable the panel to gain access to the output, if required (for example, a DOI or URL)

All outputs cited in this section must be capable of being made available to panels. If they are not available in the public domain, the administrative unit must be able to provide them if requested by RCN or the evaluation secretariate.

PhD thesis of Thomas 0yvang (defended 2018), *"Enhanced power capability of generator units for increased operational security".* Both main supervisor and co-supervisor from USN.

PhD thesis of Liubomyr Vytvytskyi (defended 2019), *"Dynamics and model analysis of hydropower system".* Both main supervisor and co-supervisor from USN.

T. Øyvang, J. K. Nøland, G. J. Hegglid, and B. Lie, "Online Model-Based Thermal Prediction for Flexible Control of an Air-Cooled Hydrogenerator," in *IEEE Transactions on Industrial Electronics*, Vol. 66, No. 8, pp. 6311-6320, Aug. 2019, doi: 10.1109/TIE.2018.2875637.

T. Øyvang, J. K. Nøland, R. Sharma, G. J. Hegglid, and B. Lie, "Enhanced Power Capability of Generator Units for Increased Operational Security Using NMPC," in *IEEE Transactions on Power Systems*, Vol. 35, No. 2, pp. 1562-1571, March 2020, doi: 10.1109/TPWRS.2019.2944673.

J. K. Nøland, M. Leandro, A. Nysveen, and T. Øyvang, "Future Operational Regimes of Bulk Power Generation in The Era of Global Energy Transition: Grid Codes, Challenges and Open Issues," 2020 IEEE Power & Energy Society General Meeting (PESGM), Montreal, QC, Canada, 2020, pp. 1-5, doi: 10.1109/PESGM41954.2020.9282001.

S. Monshizadeh, G. J. Hegglid, and S. T. Hagen, "Optimal Dispatch of Active Power Using Classical And Artificial Methods On The Distribution Networks," *2019 7th International Youth Conference on Energy (IYCE)*, Bled, Slovenia, 2019, pp. 1-4, doi: 10.1109/IYCE45807.2019.8991599.

4. Details of the impact (indicative maximum 750 words)

This section should provide a narrative, with supporting evidence, to explain:

- How the research underpinned (made a distinct and material contribution to) the impact
- The nature and extent of the impact

The following should be provided:

- A clear explanation of the process or means through which the research led to, underpinned or made a contribution to the impact (for example, how it was disseminated, how it came to influence users or beneficiaries, or how it came to be exploited, taken up or applied).
- Where the submitted administrative unit's research was part of a wider body of research that contributed to the impact (for example, where there has been research collaboration with other institutions), the case study should specify the particular contribution of the submitted administrative unit's research and acknowledge other key research contributions.
- Details of the beneficiaries – who or what community, constituency or organisation has benefitted, been affected or impacted on.
- Details of the nature of the impact – how they have benefitted, been affected or impacted on.
- Evidence or indicators of the extent of the impact described, as appropriate to the case being made.
- Dates of when these impacts occurred.

Norway's power system, with 40 % of its capacity integrated into regional and distribution networks, faces challenges due to increasing electrification and the rise of variable and less controllable wind and solar power. This necessitates more efficient system services, enhanced grid capacity, and stability in vulnerable areas. Implementation of such a system effectively holds the potential to decrease the grid tariff for every consumer, presenting a positive impact on society, the economy, and an enhancement in overall energy efficiency. The changes needed pose regulatory and task distribution challenges but also offer opportunities for safer, cost-effective operations, and higher social benefits e.g., *J. K. Nøland et. al*. To modernize the electricity grids and enable flexibility, increased transfer capacity, and new market possibilities, grid investments of around NOK 140 billion are planned in the next decade. Grid companies aim to reduce this investment through flexibility and technology, addressing stability concerns shared by Nordic Transmission System Operator's (TSOs) and European counterparts. Voltage control, crucial for stability, requires coordinated R&D involvement from all stakeholders to meet future demand for capacity, flexibility, and stability.

Our work underscores strong collaborations with stakeholders in both private and public sector – including power producers and distributors regionally (Skagerak Kraft AS and Lede AS) and nationally (Statnett SF and Statkraft AS), as well as international partners (National Renewable Energy Laboratory, NREL). This broad collaboration is directly enhancing national competence and playing a pivotal role in shaping policies and legal frameworks for hydropower.

Ongoing spin-off projects involve collaboration with Kathmandu University and NTNU, established through the NORRED II application in 2020. Further, new potential collaborations have been initiated with the National Renewable Energy Laboratory (NREL) in the USA, following an initial contact at the FME HydroCen Summit in spring 2020. Leveraging USN's expertise in both academia and hydropower industry management, HydroCen's research and spin-off projects address central and emerging issues.

These endeavors introduce peripheral concerns that, from USN's perspective, hold potential to enhance the value of hydropower, necessitating further research for clarity and implementation preparation. A crucial aspect is the exploration of state estimation to optimize power systems and minimize transmission losses, requiring changes in local and control center functionality. Evaluating the need for a marketplace for reactive power as an ancillary service is also emphasized to incentivize power producers in loss reduction.

HydroCen's practice of MSc and PhD candidates producing annual concise flyers on their theses serves as an effective communication initiative, structuring candidates' work and promoting it within the industry. Additionally, *Vytvytskyi* (ph.d. thesis from 2016 - 2019) developing the OpenHPL Modelica simulation library, funded externally, have benefited from HydroCen's support, collaborating with industry players like Statkraft, contributing valuable knowledge within modeling and control to everyday operations. Interactions with NTNU on the use of OpenHPL and other Modelica libraries for laboratory modeling are also under consideration.

5. Sources to corroborate the impact (indicative maximum of ten references)

1. *HydroCen, Project period (*2016*– 2024)*
   https://www.ntnu.no/hydrocen

2. *System optimization between power producer and grid owners for more efficient system services. Project period (2021–2025).*

https://prosjektbanken.forskningsradet.no/project/FORISS/326673?Kilde=FORISS&distribution=Ar&chart=bar&calcType=funding&Sprak=no&sortBy=date&sortOrder=desc&resultCount=30&offset=0&Geografi.2=Kongsberg

3. Hydro-Himalaya Project:
   https://huc-hkh.org/hydro-himalaya-project

[USN_IMS] [Case number 1]

Institution: University of South-Eastern Norway (USN)
Administrative unit: Department of Microsystems (IMS)
Title of case study: CIUS – Centre for Innovative Ultrasound Solutions
Period when the underpinning research was undertaken: 2015-2024
Period when staff involved in the underpinning research were employed by the submitting institution: 2015-2024
Period when the impact occurred: 2015-2024

1. Summary of the impact (indicative maximum 100 words)

SFI CIUS has strengthened the ultrasound transducer laboratory at IMS, establishing it at an internationally advanced level and given us a national role as Norway's laboratory for ultrasound transducer research. CIUS has established excellent communication channels between us and other universities, helping us to coordinate and distribute research tasks within the Norwegian ultrasound research community. A major part of Norway's ultrasound high-tech industry is in Horten, close to our lab. Part of our research lab's mission is to support this industry with competence and good candidates. This has been strengthened and systemised thorough CIUS. A confirmation of our impact is that 8 PhD candidates from our lab and several MSc-candidates are employed in R&D positions in the Norwegian ultrasound industry. Our lab has also delivered prototype transducers to Norwegian startup-companies. Several of the research projects in CIUS has contributed to industrial development, and medical technology oriented projects will contribute to improved health.

2. Underpinning research (indicative maximum 500 words)

Some key findings from our research in CIUS are

- An innovative design for multi-bandwidth transducers for use in ultrasound mediated drug-delivery. This was the result of Kenneth K. Andersen's PhD-project. A small production series of transducers developed in this research were fabricated, either by USN or by the spin-off company ReLab founded by Andersen and a colleague. These transducers have been used in preclinical studies by CIUS-partner Exact Therapeutics AS at the Institute of Cancer Research, London, TGen in Phoenix, Az, Haukeland University Hospital and at other locations. Researched and designed between 2016 and 2020, the transducers are still used in preclinical trials, the latest series was fabricated in 2023.
- Applicability of novel single-crystal ferroelectrics in sonar transducers. This was the project of industrial PhD-candidate Ellen Sagaas Røed from Kongsberg Discovery. Røed was not directly funded by CIUS, but the research environment from CIUS created synergies that lifted her work considerably. This was done between 2018 to 2022.
- Development of a combined bulk piezoelectric transmitting and a capacitive micromachined receiving transducer to obtain a very large bandwidth transducer for nonlinear medical imaging. This is the research of postdoc Tung Manh and PhD candidate Hong Duy Le and is still ongoing. The project builds on research from 2014, while the design of an array transducer for medical imaging started 2020.
- Better understanding of nonlinear phenomena in piezoelectric ultrasound transducers. In addition to the improved fundamental understanding, this knowledge is important when optimising medical transducers second harmonic diagnostic imaging and other nonlinear clinical ultrasound methods. This is the work of PhD-candidate Thong Huynh, starting in 2018 and still ongoing.

- New bonding and assembly methods for ultrasound transducers for harsh environments, e.g. by replacing polymer adhesives with metal bondlines. This will improve reliability and performance in transducers used at high pressures and temperatures, e.g. for oil well inspection, but the research will also contribute to improved reliability in transducers under standard environmental conditions. The later phase of this project focuses on transducers for extreme temperatures, up to 550°C. This research is done by PhD-students Per Kristian Bolstad and Josh Hoi Yi Siu, starting in 2018 and still ongoing
- Better understanding of loss mechanisms and heat generation in sonar transducers. Research of PhD-candidate Marcus Wild from 2016 to 2019.
- Improved analytical models for piezoelectric micromachined transducers (PMUTs). This will provide essential tools when developing PMUTs into commercially viable transducers. Research of PhD-candidate Amirfereydoon Mansoori from 2018 to 2023.

Post Doc and PhD-candidates
PhD Candidate Marcus S. Wild 2016 – 2019
PhD Candidate Kenneth K. Andersen 2016 - 2020
PhD Candidate Thong Huynh 2018 - 2023
PhD Candidate Ellen Sagaas Røed 2018 - 2022
PhD Candidate Per Kristian Bolstad 2018 - 2023
PhD Candidate Amirfereydoon Mansoori 2018 - 2023
PhD Candidate Duy Hoang Le 2021 - 2024
PhD Candidate Josh Hoi Yi Siu 2022 - 2025
Post Doc Mansoor Khan 2022 - 2023

Faculty members
Professor (PI) Lars Hoff
Post Doc / Associate Professor: Tung Manh
Associate Professor II: Martijn Frijlink
Associate professor Karl Thomas Hjelmervik (Started 2022)

Faculty members central in some projects, but not in the overall core team
Professor Knut E. Aasmundtveit
Associate Professor Hoang Vu Nguyen
Professor Einar Halvorsen
Professor Karina Hjelmervik

3. References to the research (indicative maximum of six references)

1) K. K. Andersen, M. E. Frijlink and L. Hoff, "A Numerical Optimization Method for Transducer Transfer Functions by the Linearity of the Phase Spectrum," in IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, vol. 66, no. 1, pp. 71-78, Jan. 2019, doi: 10.1109/TUFFC.2018.2882247.

2) Andersen KK, Healey A, Bush NL, Frijlink ME, Hoff L. A Harmonic Dual-Frequency Transducer for Acoustic Cluster Therapy. Ultrasound Med Biol. 2019 Sep;45(9):2381-2390. doi: 10.1016/j.ultrasmedbio.2019.04.008. Epub 2019 Jun 21. PMID: 31230911.

3) Marcus Wild, Martin Bring, Einar Halvorsen, Lars Hoff, and Karina Hjelmervik, “The challenge of distinguishing mechanical, electrical and piezoelectric losses”, J Acoust Soc Am, 144, 2128-2134, (2018) https://doi.org/10.1121/1.5057443

4) E. S. Røed, M. Bring, F. Tichy, A. Henriksen, E. -M. Åsjord and L. Hoff, “Optimization of Matching Layers to Extend the Usable Frequency Band for Underwater Single-Crystal Piezocomposite Transducers”, in IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, vol. 69, no. 2, pp. 803-811, Feb. 2022, doi: 10.1109/TUFFC.2021.3132390.

5) P. K. Bolstad, M. E. Frijlink, T. Manh and L. Hoff, "Estimating Effective Material Parameters of Inhomogeneous Layers Using Finite Element Method," in IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, vol. 69, no. 12, pp. 3402-3410, Dec. 2022, doi: 10.1109/TUFFC.2022.3220371.

6) T. Huynh, G. U. Haugen, T. Eggen and L. Hoff, "Nonlinearity in a Medical Ultrasound Probe Under High Excitation Voltage," in IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, vol. 68, no. 3, pp. 784-795, March 2021, doi: 10.1109/TUFFC.2020.3021981.

4. Details of the impact (indicative maximum 750 words)

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- Details of the nature of the impact – how they have benefitted, been affected or impacted on.
- Evidence or indicators of the extent of the impact described, as appropriate to the case being made.
- Dates of when these impacts occurred.

We have chosen to focus this on the concept *Multi-bandwidth transducers* , a concept that unites several of our PhD research projects within different application areas, and illustrate this by a few selected cases. As mentioned elsewhere, we also have other research topics, notably transducers for harsh environments and more fundamental theoretical studies.

Multi-bandwidth transducers have been a central research topic throughout the CIUS phase and is common for several of the PhD-projects. The limited bandwidth of existing ultrasound transducers is a challenge for several applications motivates our research on this topic. Some application examples are.

- Modern medical diagnostic ultrasound imaging uses the nonlinear properties of biological tissue to enhance image quality, e.g. by second harmonic imaging, where the image is formed from echoes received at twice the transmitting frequency. This requires a transducer with a large bandwidth. Future diagnostic methods may also benefit from information in even higher (superharmonics), which is not possible with conventional technology.
- Therapeutic use of ultrasound, especially ultrasound mediated drug delivery, is an intense research field world-wide. It has demonstrated promising results for cancer treatment, where it can allow a more target-specific delivery of chemotherapeutics.

- In ocean exploration, there is an ongoing transition to small autonomous underwater vehicles, AUVs. This opens new opportunities, but also introduces new challenges for the sonar systems, specifically by requiring compact lightweight sonar systems with low power consumption.

Examples of our research in CIUS to contribute to these challenges is:

- Kenneth K Anderssen designed and developed various innovative new designs for multi-band medical transducers during his PhD-project. He collaborated with researchers from the CIUS industrial partner Exact Therapeutics AS. Exact is a Norwegian startup-company developing a new concept for cancer therapy using ultrasound and microbubbles to selectively deliver chemotherapeutic agents to tumours. Their agent is in clinical trials and has demonstrated promising results. With funding from CIUS, Andersen designed a novel transducer using the fundamental resonance frequency and its 5^{th} harmonic to cover the frequency bands needed to activate and release the chemotherapeutic agent in Exact's particles at a selected location *in vivo* in preclinical studies. These transducers were put in small-scale production, some by Andersen's spin-off company ReLab. His transducers have been used with success in Exact's preclinical studies at prestigious cancer research labs, including the Institute of Cancer Research in London and the Translational Genomics Research Institute in Phoenix, Az, and in Norway at Haukeland University Hospital and at NTNU.
- A novel class of piezoelectric materials, called single crystal ferreoelectrics, have been in regular use in high-end medical ultrasound transducers for more than a decade, but their use in underwater sonar is still very limited. Compared to conventional piezoceramic materials, the single crystals offer superior electro-mechanical coupling, opening for a larger bandwidth. However, the materials are expensive, fragile and difficult to handle compared to the ceramic materials. Røed developed a concept for sonar transducers using these single crystals to stretch the usable frequency band beyond what is possible in conventional transducers. Her idea was not to create a single wideband pulse, but rather obtain one transducer that could transmit ultrasound pulses within several bands. She investigated several concepts theoretically, verified her theory by FEM studies, and had prototypes fabricated. These novel sonar designs can allow a single transducer to fulfil the tasks of 3 or 4 conventional transducers, which is especially beneficial for the transition to small UAVs with limited space for payload and limited available power. This can open new opportunities in ocean exploration and justify the higher cost and more difficult fabrication per transducer.
- Today's transducers for diagnostic medical imaging primarily use piezoelectric materials vibrating in in bulk mode to transmit and receive pulses. Micromachined transducers have been promising since the late 1990s but have seen very limited commercial use. In theory, capacitive micromachined ultrasound transducers, CMUTs, offer near unlimited electromechanical coupling and excellent integration to front-end electronics, but this has been difficult to obtain in practical devices. A main limitation of CMUTs is their inherit nonlinearity, making it difficult to avoid harmonic distortion in the transmitted pulses. This is a serious problem for modern diagnostic imaging, where harmonics from the tissue are used to improve image quality. The native tissue harmonics will be contaminated from harmonics from the transducer. Our solution to this is to combine the best of the two technologies into a single device we call a dual-frequency hybrid transducer. Here, the excellent transmit sensitivity and linearity of a bulk piezoelectric is combined with the large bandwidth and configurability of a CMUT receiver. This was the topic of the postdoc project of Tung Manh staring in 2014. He successfully developed and demonstrated a single-element hybrid transducer in collaboration with the University of Rome, GE Parallel Design in Nice and CIUS-partner GE Vingmed Ultrasound. The next phase of this project has been to develop an array transducer for imaging with Vingmed's ultrasound scanners. This is the topic of Phd-student Hoang Duy Le. He has successfully developed the low frequency transmitting part of the transducer array and shipped it to Rome for integration with the CMUT. Unfortunately, problems with the delivery of the CMUT has delayed the project, and

we are now testing the concept with a PVDF film receiver. However, we have finished theoretical studies and simulations and have developed and demonstrated fabrication procedure for the novel concept, and are still waiting to get the combined piezoelectric-CMUT array. If successful, this transducer concept can significantly improve the image quality of medical diagnostic images and open new opportunities to obtain more information from medical ultrasound images.

I5. Sources to corroborate the impact (indicative maximum of ten references)

The CIUS websidte: https://www.ntnu.edu/cius/about

Establishing Ultrasound laboratory: Annual Report 2016 (ntnu.edu)

References

Svein Erik Måsøy, CIUS director and assoc. prof., NTNU
Frank Tichy, R&D manager. Kongsberg Discovery
Erik Swensen, Vice president R&D, Medistim AS
Svein Kvåle, Co-founder and COO, Exact Therapeutics AS
Jean-Francois Gelly, former manager GE Parallel Design, Sophia Antipolis, France

[USN_IMS] [Case number 2]

Institution: University of South-Eastern Norway (USN)
Administrative unit: Department of Microsystems (IMS)
Title of case study: Arm neuroprosthesis equipped with artificial skin and sensorial feedback (ARMIN)
Period when the underpinning research was undertaken: 2019 - 2023
Period when staff involved in the underpinning research were employed by the submitting institution: 2019 - 2023
Period when the impact occurred: from 2019 until present

1. Summary of the impact (indicative maximum 100 words)

The department of microsystems are involved in multiple international research and development projects. ARMIN is a collaboration project between partners in Romania and Norway within the EEA grants. The grants aim at contribution to a more equal Europe, both socially and economically, and to strengthen the relations between Iceland, Liechtenstein and Norway, and the 15 Beneficiary States in Europe.
ARMIN involved 5 partners in Romania in addition to USN in Norway. It included both academia, institute sector, medical academy, hospital, and an industrial company. In addition to the research results in the health technology area and the strengthened relationship between Romania and Norway, it directly contributed to the follow-up NerveRepack KDT-JU project consisting of 27 partners from 10 countries across Europe.

2. Underpinning research (indicative maximum 500 words)

The key research results are mainly published in the articles and theses listed in the next section. It is related to the research and development of a neuroprosthesis equipped with artificial skin and sensorial feedback. Although the overall goal at the beginning of the project was to have a neuroprosthesis prototype ready during the project period, it did not complete the task, but still ended up with significant results within certain areas of research focus. At USN the research was concentrated around particularly three interesting areas.
1) Micro fabrication of an implantable flexible cuff electrode. Cuff electrodes are designed to acquire neural signals directly from nerve fascicles, with subsequent use of the signals to control hand grips in the upper limb neuroprosthesis. Biocompatible materials, such as Au and PDMS are typically used to make electrodes suitable for implants. We studied techniques to transfer etched gold patterns to a PDMS film to produce soft, flexible PDMS-Au cuff electrodes. The gold tracks were fabricated on a silicon wafer using standard photolithography and then transferred to the PDMS substrate by two different methods, a chemical-free transfer and an MPTMS transfer method. In both methods, we compared some relevant tuning parameters, such as curing temperature and ratio of the PDMS, to improve the Au-pattern transfer. We achieve the transfer of Au onto PDMS using the MPTMS method.
2) Design and laboratory prototyping of an implantable electronics module for nerve signal acquisition, digitalization and wireless communication. The module included the front-end circuit necessary to amplify the motor nerve pulse signal, which has an amplitude of approximately 5–10 mV. It consisted of an input filter, a pre-amplifier, to stages of band-pass and high-pass filtering in combination with programmable gain amplifiers. The processed signal was the digitized and wirelessly transmitted using Bluetooth low energy. A LiPo battery was used as power source.
3) Testing of various machine learning algorithms in MATLAB for possible use in decoding of the acquired nerve signals into the correct hand grip. A master thesis in the project focused on

investigating an algorithm for classification of EMG signals where Empirical Mode Decomposition technique and feature extraction techniques were used. Total eight features were extracted. Classification of EMG signals from an online database were done over various feature combinations and results were analyzed.

Names of the key researchers and what positions they held at the administrative unit at the time of the research:

- Lars-Cyril Blystad, project leader at USN – Associate Professor
- Per Øhlckers – Professor
- Kristin Imenes – Deputy head of Department; Associate Professor
- Giuseppe Schiavone – Associate Professor
- Luca Marchetti – Associate Professor II
- Birigitte Kasin Hønsvall – Chief engineer
- Jairo Ramírez-Sarabia – Ph.d Research Fellow
- Saad Rabbani – Master student
- Samarbir Singh – Master student

3. References to the research (indicative maximum of six references)

- **Authors**: Moldovan, C. A.; Ion, M.; Dragomir, D. C.; Dinulescu, S.; Mihailescu, C.; Franti, E.; Dascalu, M.; Dobrescu, L.; Dobrescu, D.; Gheorghe, M.-I.; Blystad, L.-C.; Øhlckers, P.; Marchetti, L.; Imenes, K.; Hønsvall, B. K.; Ramírez-Sarabia, J.; Lascar, I.; Neagu, T. P.; Raita, S.; Costea, R.; Barbilian, A.; Gherghiceanu, F.; Stoica, C.; Niculae, C.; Predoi, G.; Carbunaru, V.; Ionescu, O.; Oproiu, A. M.
- **Title**: "Remote Sensing System for Motor Nerve Impulse"
- **Year of publication**: 2022
- **Type of output**: Journal article – Sensors, volume 8, https://doi.org/10.3390/s22082823

- **Authors**: Ramírez-Sarabia, Jairo; Rabbani, Saad; Blystad, Lars-Cyril; Imenes, Kristin.
- **Title**: "Microfabrication of biocompatible cuff electrodes for upper-limb neuroprosthesis"
- **Year of publication**: 2022
- **Type of output**: Conference article – 2022 IEEE 9th Electronics System-Integration Technology Conference (ESTC); https://doi.org/10.1109/ESTC55720.2022.9939555

- **Authors**: Imenes, Kristin; Blystad, Lars-Cyril; Marchetti, Luca; Hønsvall, Birgitte Kasin; Øhlckers, Per; Rabbani, Saad; Moldovan, Carmen; Ionescu, Octavian; Franti, Eduard; Dascalu, Monica; Dobrescu, Lidia; Dobrescu, Dragos; Barbilian, Adrian; Lascar, Ioan; Oproiu, Ana Maria; Neagu, Tiberiu; Raita, Stefani; Costea, Ruxandra; Carbunaru, Vlad.
- **Title**: "Implantable Interface for an Arm Neuroprosthesis"
- **Year of publication**: 2021
- **Type of output**: Conference article – 2021 23rd European Microelectronics and Packaging Conference (EMPC), https://doi.org/10.23919/EMPC53418.2021.9585011

- **Authors**: Blystad, Lars-Cyril; Øhlckers, Per; Marchetti, Luca; Franti, Eduard; Dascalu, Monica; Ionescu, Octavian; Dobrescu, Dragos; Dobrescu, Lidia; Niculae, Catalin; Dragomir, David Catalin; Hønsvall, Birgitte Kasin; Opris, Cristian Ovidiu; Imenes, Kristin; Ion, Marian; Oproiu, Ana Maria; Pascalau, Ana-Maria; Carmen, Moldovan; Firtat, Bogdan; Ristoiu, Violeta; Gheorghe, Roxana; Barbilian, Adrian.
- **Title**: "Bidirectional neuroprosthesis system integration"
- **Year of publication**: 2020
- **Type of output**: Conference article - 2020 IEEE 8th Electronics System-Integration Technology Conference (ESTC), https://doi.org/10.1109/ESTC48849.2020.9229697

4. Details of the impact (indicative maximum 750 words)

Apart from the direct research results in the ARMIN project, the research led to a closer relation and collaboration between Norway and Romania, thus fulfilling one of the main goals of the EEA Grants. It also contributed to a more socially equal Europe, partially fulfilling the other main goal of the Grants. The participants in the collaboration span over academia, research institute, medical academy, hospital and industry company. The specific project participating partners were: Project coordinator "Politehnica" University of Bucharest, Romania, project partner Academy of Medical Sciences of Romania, Romania, project partner Emergency Clinical Hospital of Bucharest, Romania, project partner National Institute for Research and Development in Microtechnologies, Romania, project partner Areus Technology, Romania, and project partner University of South-Eastern Norway, Norway.

The Norwegian partner USN went to Romania on several occasions for project meetings, project experiments and also for conference participation. Due to the Covid-19 pandemic and following lock-down, travelling was unfortunately limited during that period. Close collaboration was still maintained via weekly digital project meetings.

Based on the research results achieved in the ARMIN project a new larger European collaboration emerged. A strong consortium of 27 partners from 10 countries spread over academia, research institutes, medical entities and industrial companies joined forces in a now granted KDT-JU project named NerveRepack. NerveRepack is a research project aiming at developing implantable neuronal interfaces for bidirectional communication with exoprostheses and exoskeletons, enhancing mobility and sensory experience for individuals with amputations or paralysis.

The ARMIN project will in this way have an impact within health and quality of life, beyond academia.

5. Sources to corroborate the impact (indicative maximum of ten references)

https://armin-see.eu/
https://www.imt.ro/projects/rn.htm

https://www.nerverepack.eu/

https://eeagrants.org/about-us

https://www.usn.no/nyhetsarkiv/forsker-pa-kunstig-arm-styrt-av-hjernen

https://openarchive.usn.no/usn-xmlui/handle/11250/2765122
Rabbani, Saad – Master thesis

[USN_IMS] [Case 3]

Institution: University of South-Eastern Norway
Administrative unit: Department of microsystems
Title of case study: Super Capacitors
Period when the underpinning research was undertaken: 2009-Present
Period when staff involved in the underpinning research were employed by the submitting institution: 2009-Present
Period when the impact occurred: 2019

Summary of the impact (indicative maximum 100 words)
Based upon research at USN IMS from 2009, nanoCaps was incorporated on March 29th, 2021 to commercialise supercapacitor electrodes using interconnected crosslinked carbon nanotubes. With this disruptive technology, nanoCaps offers an increase of energy and power storage be between 2.2 to 3.6 times compared to current industry standard, depending on packaging of the products. The increase of power and energy density is 3 times on average. The global market for double sided supercapacitors is estimated to be around 3 billion Euros in 2023 (TAM) with an expected CAGR in the range from 14 to 20% per year in the coming years.

1. Underpinning research (indicative maximum 500 words)

The technology is based upon interconnected and cross-linked carbon nanotubes being deposited on substrates like aluminium foil or silicon to create the electrodes to be assembled into supercapacitor devices together with other parts like electrolyte and electrode separators. The assembled devices are mostly cylindrical, prismatic (cubic box) or surface mount packages. nanoCaps will use modified state of the art semiconductor grade Atmospheric Chemical Vapour Deposition (APCVD) and/or Plasma Enhanced Chemical Vapor Deposition (PECVD) to create the electrode film with interconnected cross-linked carbon nanotubes on the electrode substrate.

Starting from 2009, the core research group at USN lead by professor Xuyuan Chen and professor Per Ohlckers refined the technology stepwise until a breakthrough in 2019 with the key performance parameter specific area capacitance reaching ~2 500 mF, disruptively better than industry-best performance of ~700 mF.

The following IPR is secured:
At present we have 3 awarded patents:
CNT on silicon-grass Supercapacitors: Patent: Xuyuan Chen, Pai Lu, Ohlckers, Per Alfred: "On-chip Supercapacitor with Silicon Nanostructures" **NO20170000334 20170307, WO2018EP55471 20180306** Accepted January 30th, 2020.
Interconnected Crosslinked CNT: Patent: Xuyuan Chen and Pai Lu: "Deposited carbon film on etched silicon for on-chip supercapacitor" **EP3593371B1**. Accepted May 19th, 2021.
CNT on microstructured flexible foil Supercapacitors: Patent: Kang Du, Xuyuan Chen, Per Ohlckers: "Direct growth cross-linked carbon nanotubes on microstructured metal substrate for supercapacitor application" **P6222NO00** Accepted November 2, 2021.

At present, the last patent describes the technology innovation we are now commercializing. We have also filed a patent application in 2023: Per Ohlckers: "Fabricating an electrode for a lithium-ion capacitor".

The research work is also disseminated in popular press, conferences and scientific papers.

2. References to the research (indicative maximum of six references)

1. Xuyuan Chen, Pai Lu, Ohlckers, Per Alfred: "On-chip Supercapacitor with Silicon Nanostructures" Patent: NO20170000334 20170307, WO2018EP55471 20180306 Accepted January 30th, 2020.
2. Xuyuan Chen and Pai Lu: "Deposited carbon film on etched silicon for on-chip supercapacitor" Patent EP3593371B1.
3. Kang Du, Xuyuan Chen, Per Ohlckers: "Direct growth cross-linked carbon nanotubes on microstructured metal substrate for supercapacitor application" Patent P6222NO00.
4. Per Øhlckers: «Hybrid micro-nano structures» Patentsøknad levert 24.mai 2022.
5. Pai Lu, Einar Halvorsen, Per Ohlckers, Lutz Müller, Steffen Leopold, Martin Hoffmann, Kestutis Grigoras, Jouni Ahopelto, Mika Prunnila, Xuyuan Chen: "Supercapacitors based on nano scaffold of silicon grass coated by titanium nitride" Electrochemistry Communications, 70 (2016) 51–55. dx.doi.org/10.1016/j.elecom.2016.07.002.
6. Pai Lu, Einar Halvorsen, Per Ohlckers, Lutz Müller, Steffen Leopold, Martin Hoffmann, Kestutis Grigoras, Jouni Ahopelto, Mika Prunnila, Xuyuan Chen: "Ternary composite Si/TiN/MnO2 tape nanorod array for on-chip supercapacitor" Electrochimica Acta 248 (2017) 397–408. dx.doi.org/10.1016/j.electacta.2017.07.162.
7. Pai Lu, Xuyuan Chen, Per Ohlckers, Einar Halvorsen, Martin Hoffmann and Lutz Mûller: "DRIE Nanowire Arrays Supported Nano-Carbon Film for Deriving High Specific Energy Supercapacit On-Chip" Journal of Physics Conference Series 1837(1):012005. DOI: 10.1088/1742-6596/1837/1/012005.
8. Du, Kang; Yu, Chengjun; Øhlckers, Per; Chen, Xuyuan: "Low equivalent series resistance (ESR) silicon-based on-chip supercapacitors" *2020 IEEE 8th Electronics System-Integration Technolo Conference (ESTC)*. IEEE 2020 ISBN 978-1-7281-6293-5. **DOI:** 10.1109/ESTC48849.2020.92298
9. Populærvitenskapelig omtale i tidsskriftet "Elektronikk" 5. mai 2022: www.elektronikknett.no/bedrift-eu-forskning/det-er-na-det-begynner/3090864.
10. Populærvitenskapelig omtale i tidsskriftet "Elektronikk" 5. mai 2022: www.elektronikknett.no/bedrift-eu-forskning/det-er-na-det-begynner/3090864Populærvitenskapelig omtale i tidsskriftet "Teknisk Ukeblad" 20. septembe 2022: www.tu.no/artikler/bygger-det-de-mener-er-verdens-mest-energitette-superkondensatorer/522327/?key=yiLODBRq.

4. Details of the impact (indicative maximum 750 words)

The potential of the nanoCaps electrode used in supercapacitors: The high capacities with the newly developed electrode will make the supercapacitors might take over for ordinary batteries in more applications than today. The supercapacitors with nanoCaps electrodes will achieve between 2.2 to 3.6 times higher energy and power density than the existing supercapacitors. And store at the same time more energy in the same volume or weight, making them much more practical and environmentally friendly for a variety of applications such as electric vehicles, renewable energy storage, and mobile devices.
Supercapacitors are safer than batteries and will be charged in seconds when batteries use hours. They have a significantly longer lifetime than batteries with 1 million cycles when batteries have 3000 to 5000 cycles. Supercapacitors are generally more expensive than batteries, but a new supercapacitor with higher energy and power density could potentially reduce the overall lifetime cost of energy storage systems by requiring fewer cells to achieve the same performance.

Supercapacitors with our electrode will play a rapidly increasing role in renewable and sustainable energy generation and storage systems in the future, ensuring added flexibility and security. Supercapacitors of today already excel in many virtues like high power capacity, more than 90% energy efficiency, more than 10 years lifetime, cycle life up to 1 million and low lifetime cost. Low temperatures do not affect the behaviour.

The total world supercapacitor market is estimated by a lot of market research companies. An average and estimate from 8 market surveys gives total market in 2025 to be 5,3 B€. CAGR varies from 10-20%. 40% are not Pseudocapacitors which leave TAM to be 3 B€ in 2025.
Based on information from two of our potential customers, we know from meetings with main suppliers that approximately 25% of the costs of making a cylindrical cell are the electrodes. Knowing that and that Maxwells profit is about 20%, a verified estimate is that SAM is 24% of the total market for double sided supercapacitors.
The Global Coin Cell Supercapacitors Market will grow from € 235 Million in 2022 to € 500 Million in 2030. CAGR is 10%. The total market in 2025 is € 300 Million. Due to the increase of energy density and competitive price, 60% of the market is a realistic estimate for SAM. The 40% left will be serviced of cells with lower capacitance and density.
Until 2027, we estimate SOM to be 40% of the total market for electrodes. After that, the impact of our electrode is expected to increase the demand for ultracapacitors with our electrodes.

5. Sources to corroborate the impact (indicative maximum of ten references)

To our knowledge no other research group works with supercapacitor electrodes based upon interconnected crosslinked carbon nanotubes, and therefore we do not have a list references here to corroborate the impact.

University of South-Eastern Norway and Department of Process, Energy and Environmental Technology – Case 1

Institution: University of South-Eastern Norway / USN
Administrative unit: Department of Process, Energy and Environmental Technology, PEM
Title of case study: Hydrogen Safety
Period when the underpinning research was undertaken: 2012-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2012-2022
Period when the impact occurred: 2012-2022

1. Summary of the impact (indicative maximum 100 words)

The research group of Process Safety, Combustion, and Explosions conducts research on industrial safety and applied research with a focus on new energy carriers and fuels. The overall research goal for the projects is to generate new knowledge for reducing the risk and consequences of accidents and contribute to a safer introduction of more sustainable energy conversion. A main focus in the society and in the research group has been Hydrogen safety.
The most important impacts are results achieved in collaboration with the partners in projects. New knowledge created by the research group has contributed to technology development for these specific projects and other projects where this knowledge is needed.

2. Underpinning research (indicative maximum 500 words)

The research group is a partner in several projects together with the industry to develop new technology for hydrogen and ammonia production, storage, and end-use. These projects have created new knowledge needed for a transition to carbon-neutral energy carriers and will create value for the industry partners in the projects. Especially three projects which are central in this research are *Innovation project HyLOCD* on the development of maritime fuel cells; *Green Platform Underwater storage of hydrogen* for development of storage technology at the sea bed; *Green Platform Ammonia as a hydrogen vector for the energy market* on development of technology for production of hydrogen from ammonia. The research group is also involved in development of training of first responders to handle new energy carriers and fuels in projects HyResponder (H2020) and H2Konstabel (NFR). The main contributions in the projects have been related to experimental research, numerical calculations and within image processing.

In the period 2012-2022, the research group has contributed in the following projects:

- FME-MoZEES (NFR, 2017 – 2025): MoZEES focuses on battery and hydrogen value chains, systems, and applications where Norway can take a leading position in the future.
- FME-HYDROGENi (NFR, 2022 – 2030): Norwegian research and innovation center for hydrogen and ammonia (2022 – 2030)
- HyTunnel-CS (EU, 2018 – 2022): The safe use of hydrogen in tunnels and confined spaces.
- HyRESPONDER (EU, 2020 – 2023:): European training network for first responders
- H2Konstabel (NFR, 2022 – 2024):
- H2Maritime (NFR, 2018 - 2022): Fuel Cell in the maritime systems, bunkering, and safety.
- HyLOCD (NFR, 2021 - 2024): Research and development of a hydrogen loss of containment detection method for maritime fuel cell systems.
- SH2IFT-2 (NFR, 2021 - 2025): Safe hydrogen fuel handling and use for efficient implementation.

- Green Platform (NFR, 2022 - 2025): Subsea storage of hydrogen
- Green Platform (NFR, 2022 - 2025): Ammonia as a hydrogen vector in the energy market
- HySchool (NFR, 2022-2030): Norwegian research school on hydrogen and hydrogen-based fuels
- H2NOR (IN, 2021 – 2024): For safe maritime fuel cells
- Gen2Energy (RFF, 2021 - 2022)

National partners in these projects have been:

- IFE - Institute for Energy Technology
- Norwegian Defence Research Establishment (FFI)
- The Norwegian Defence Estates Agency (NDEA)
- Norwegian Hydrogen Forum and Norwegian Battery Safety Forum
- Wärtsila, Equinor, Norsk Hydro, Yara, Corvus Energy, Statkraft, Ineos, Sintef,
- And research partners in MoZEES, HYDROGENi, and SH2IFT-2.

International partners have been:

- IDERS - The Institute for Dynamics of Explosions and Reactive Systems
- IEA Hydrogen TPC – Hydrogen Safety Task 19, 31,37, and 43.
- HySafe: The EC Network of Excellence for Hydrogen Safety "HySafe."
- ICARE: Institute of Combustion, Aerothermal, Reactivity, and Environment

3. References to the research (indicative maximum of six references)

Lach, Agnieszka & Gaathaug, Andre Vagner (2021). Effect of Mechanical Ventilation on Accidental Hydrogen Releases—Large-Scale Experiments. Volume 14(11) . Energies.*Academic article*
DOI: https://doi.org/10.3390/en14113008

Henriksen, Mathias; Gaathaug, Andre Vagner & Lundberg, Joachim (2018). Determination of underexpanded hydrogen jet flame length with a complex nozzle geometry. s. 1-9. International Journal of Hydrogen Energy.*Academic article*
DOI: https://doi.org/10.1016/j.ijhydene.2018.07.019

Vågsæther, Knut; Gaathaug, Andre Vagner & Bjerketvedt, Dag (2018). PIV-measurements of reactant flow in hydrogen-air explosions. . International Journal of Hydrogen Energy.*Academic article*
DOI: https://doi.org/10.1016/j.ijhydene.2018.10.025

Sommersel, Ole Kristian; Vågsæther, Knut & Bjerketvedt, Dag (2017). Hydrogen explosions in 20′ ISO container. Volume 42(11) s. 7740-7748. International Journal of Hydrogen Energy.*Academic article*
DOI: https://doi.org/10.1016/j.ijhydene.2016.06.239

Rai, Kanchan; Bjerketvedt, Dag & Gaathaug, Andre Vagner (2014). Gas explosion field test with release of hydrogen from a high pressure reservoir into a channel. Volume 39(8) s. 3956-3962. International Journal of Hydrogen Energy.*Academic article*
DOI: https://doi.org/10.1016/j.ijhydene.2013.12.166

Gaathaug, Andre Vagner; Vågsæther, Knut & Bjerketvedt, Dag (2012). Experimental and numerical investigation of DDT in hydrogen–Air behind a single obstacle. Volume 37(22) s. 17606-17615. International Journal of Hydrogen Energy.*Academic article*
DOI: https://doi.org/10.1016/j.ijhydene.2012.03.168

4. Details of the impact (indicative maximum 750 words)

The participation in the project FME Mozees (Mobility Zero Emmision Energy Systems) has been as a main forum for Hydrogen transport and safety.

The participation in the project SH2IFT-2 (Safe Hydrogen Fuel Handling and Use for Efficient Implementation) has contributed to improved solutions for Hydrogen safety.

The participation in the project HyLOCD (Inline hydrogen loss of containment detection) has contributed to development of maritime hydrogen safety solutions.

The participation in the project HyTunnel-CS has contributed to standards and design for increased safety in European Tunnels.

5. Sources to corroborate the impact (indicative maximum of ten references)

Most of the impact are results achieved in collaboration with the partners in the projects.
Links to important projects are given below:

FME MoZEES

HyTunnel-CS – Pre-normative research for safety of hydrogen driven vehicles and transport through tunnels and similar confined spaces. Project No. 826193

HyResponder – European Hydrogen Train the Trainer Programme for Responders

Hydrogen and Fuel Cells for Maritime Applications - Prosjektbanken (forskningsradet.no)

Inline hydrogen loss of containment detection - Prosjektbanken (forskningsradet.no)

H2NOR Marine Fuel Cell Development Project - Corvus Energy

University of South-Eastern Norway and Department of Process, Energy and Environmental Technology – Case

Institution: University of South-Eastern Norway / USN
Administrative unit: Department of Process, Energy and Environmental Technology, PEM
Title of case study: CO_2 capture realizations
Period when the underpinning research was undertaken: 2012-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2012-2022
Period when the impact occurred: 2012-2022

1. Summary of the impact (indicative maximum 100 words)

The research group of Energy and CO_2 capture have conducted research on design of CO_2 capture processes for many years. This has involved equipment design, cost estimation and solvent handling. Within CO_2 capture, the research group have made contributions within Carbon Capture and Storage (CCS) and also Utilization as main areas of competence. The important impacts in the period 2012-2022 has been contributions in the realization of the full scale CO_2 capture plant in Brevik, the TCM test center at Mongstad and in cost estimation and cost optimization methods for future CO_2 capture projects.

2. Underpinning research (indicative maximum 500 words)

At USN, campus Porsgrunn, carbon capture research have been conducted for several years. The activities comprise **l**aboratory plant studies of amine-based chemical absorption, amine degradation studies., utilization of captured CO_2 in chemical product production, electrification of cement calciners combined with CO_2 capture, process simulation and cost estimation of CO_2 capture. There have been close cooperation with industry and especially contributions to the development of the CO_2 capture plant at Heidelberg materials, Brevik.

The research group of Energy and CO_2 capture has in 2022 been included in a larger research group “Energy and Environmental Research (URGENT)”. The impacts presented here are from the period 2012 to 2022.

USN has contributed in projects with measurements and correlations for estimation of physical properties of amine based solvents. This is important for both preliminary and final design of CO_2 capture plants.

The collaboration with Heidelberg Materials (earlier Norcem) in Brevik within CO_2 capture has been important. The research group has been testing out different technologies of post combustion carbon capture, performing process simulations, building experimental test rigs, performing experiments with alternative absorption agents, and performing cost estimations and cost optimizations. Several Bachelor Projects, Master projects and PhD projects have been performed with the CO_2 capture plant at Norcem as a topic. Together with other projects, this has given important contributions to establishing the first land-based CO_2-plant, including transport and storage, in Norway.

The CO_2stCap project has shown that by focusing on the most cost-effective CO_2 sources, partial capture can reduce considerably both the specific and the absolute CO_2 capture costs. The reduction of the specific cost is important to motivate the operation of carbon capture, given that this cost is related to the cost of allowances for emitting CO_2 and, therefore, could create value for CCS. The reduction of the absolute cost is important in terms of reducing the risk of the investment, which is especially important for early adopters and during the maturation of the carbon markets. More specifically, the project has performed case studies that deal with the implementation of cost-efficient carbon capture in four Nordic industries: Cement, Steel, Pulp and paper and Silicon production.

The Align-CCUS project is important for further development. For the Norwegian partners, it is Grenland that has been in focus in ALIGN-CCUS and with the establishment of the Longship project and an initiative for the development of a separate central hub to capture CO_2 from all emission sources in Grenland.

3. References to the research (indicative maximum of six references)

Wagaarachchige, Jayangi Dinesha; Idris, Zulkifli; Khatibzadeh, Ayandeh; Drageset, Audun; **Jens, Klaus-Joachim & Halstensen, Maths** (2023). Demonstration of CO2 Capture Process Monitoring and Solvent Degradation Detection by Chemometrics at the Technology Centre Mongstad CO2 Capture Plant. Volume 62(25) s. 9747-9754. Industrial & Engineering Chemistry Research.*Academic article*
DOI: https://doi.org/10.1021/acs.iecr.3c00134

Muhammad Akram, **M.H. Wathsala N. Jinadasa**, Paul Tait, Mathieu Lucquiaud, Kris Milkowski, Janos Szuhanszki, **Klaus-Joachim Jens, Maths Halstensen**, Mohammed Pourkashanian. Application of Raman spectroscopy to real-time monitoring of CO2 capture at PACT pilot plant; Part 1: Plant operational data, International Journal of Greenhouse Gas Control, 2020.
https://doi.org/10.1016/j.ijggc.2020.102969
https://doi.org/10.1016/j.ijggc.2020.102969

Lars Erik Øi; Kai Arne Sætre; Espen Steinseth Hamborg (2018). Comparison of simulation tools to fit and predict performance data of CO2 absorption into monoethanol amine at CO2 Technology Centre Mongstad (TCM). Volume 153:32 s. 230-235. Linköping Electronic Conference Proceedings. *Academic article*
DOI: https://doi.org/10.3384/ecp18153230

Sumudu S. Karunarathne, Dag A. Eimer and **Lars E. Øi**
Physical properties of MEA + water + CO2 mixtures in postcombustion CO2 capture: A review of correlations and experimental studies, Journal of Engineering, 2020.
https://doi.org/10.1155/2020/7051368
Physical Properties of MEA + Water + CO2 Mixtures in Postcombustion CO2 Capture: A Review of Correlations and Experimental Studies (hindawi.com)

Solomon Aforkoghene Aromada, Nils Henrik Eldrup and **Lars Erik Øi**
Capital cost estimation of CO2 capture plant using Enhanced Detailed Factor (EDF) method: Installation factors and plant construction characteristic factors, International Journal of Greenhouse Gas Control, 2021.
https://doi.org/10.1016/j.ijggc.2021.103394
Capital cost estimation of CO2 capture plant using Enhanced Detailed Factor (EDF) method: Installation factors and plant construction characteristic factors (usn.no) m)

Hassan Ali, , Nils Henrik Eldrup, Fredrik Normann , Ragnhild Skagestad , **Lars Erik Øi** Cost Estimation of CO2 Absorption Plants for CO2 Mitigation – Method and Assumptions, International Journal of Greenhouse Gas Control, 2019.
https://doi.org/10.1016/j.ijggc.2019.05.028
Cost Estimation of CO2 Absorption Plants for CO2 Mitigation – Method and Assumptions – ScienceDirect

4. Details of the impact (indicative maximum 750 words)

At Heidelberg Materials cement plant (earlier Norcem) a full-scale CO_2 capture plant is now built in Brevik. This is the most important part of the Northern Light project which is a full scale project including carbon capture, transport by ship and storage under the North Sea. Employees, students and PhD students at USN has contributed significantly to this project. First in the initiation phase where different alternatives were evaluated. Then in the technology development and early phase design work. Results from this work has been used in the final design from the technology supplier (Aker Solutions/ Aker Carbon Capture) and in the integration with the cement plant (Heidelberg Material). The realization phase is strictly commercial, and University staff and students are not much involved in that phase. But it is planned that USN staff and students will be involved in the performance evaluation of the plant when it is in operation.

TCM Mongstad is the world's largest test facility carbon capture facility. USN (by staff and students) have been especially involved in the activities related to the amine based carbon capture test facility. They have been involved in fitting performance data to process simulation models. They have been among the first to publish results from fitting process simulations to performance data. This has again had influence on the further test campaigns at TCM.

A specific problem in amine based carbon capture is degradation of the solvent. This is one of the research areas at USN in Porsgrunn. There have been performed test campaigns at TCM Mongstad where staff from USN has been involved. This has influenced on further test campaigns.

The PEM department has collaborated with several projects funded by CLIMIT (a cooperation between Gassnova and NFR) together with SINTEF Industry about CO_2 capture. Several of these projects have been about simulation and cost estimation of amine based carbon capture plants. This work has ended up with PhD works who are giving methods for early phase cost estimation of amine based CO_2 capture plants. This is important in the evaluation of future CO_2 capture projects.

5. Sources to corroborate the impact (indicative maximum of ten references)

The Longship White Paper available in English (ccsnorway.com)

Karbonfangstanlegg på Norcem: – Dette er et resultat av langsiktig forskning – Universitetet i Sørøst-Norge (usn.no)

Technology Centre Mongstad | Carbon technology testing (tcmda.com)

ALIGN-CCUS - Climit

Cutting Cost of CO2 Capture in Process Industry (CO2stCap) – Climit

University of South-Eastern Norway, USN School of Business [1]

Institution: University of South-Eastern Norway
Administrative unit: USN School of Business
Title of case study: BETTEReHEALTH: Human, technical and political factors for better coordination and support of e-health in Africa
Period when the underpinning research was undertaken: 2020-2023
Period when staff involved in the underpinning research were employed by the submitting institution: 2020-2023
Period when the impact occurred: 2020-2023

1. **Summary of the impact** (indicative maximum 100 words)

The BETTEReHEALTH (BeH) project aims to provide better health outcomes and achievement of Universal Health Coverage and SDGs by informing and strengthening end-user communities and policymakers in making the right decisions to implement, integrate and use eHealth in Africa. This is done through a bottom-up evidence-based holistic approach increasing the level of international cooperation in eHealth to support evidence-based implementation of eHealth.

BeH have successfully established four Regional Hubs in Africa consisting of stakeholders with diverse backgrounds including policymakers, health services, technical implementers and academic research. The project has organised 10 regional workshops and 2 international conferences, providing valuable opportunities for sharing experiences and discussing challenges between policymakers and other eHealth stakeholders. The registries for eHealth solutions and policies were launched, and an eHealth policy roadmap and strategic implementation plans have been developed for better eHealth services.

The project has further submitted 31 deliverables documenting best-practices and useful knowledge regarding human, technical, and public policy factors for successful eHealth implementation in Africa. The research results have been presented and discussed at 24 international conferences expanding the outreach of BeH among eHealth stakeholders in various African countries. Seven research papers have been published in peer-reviewed international journals. An exploitation plan has also been developed to sustain the regional hubs beyond the project period.

2. **Underpinning research** (indicative maximum 500 words)

Between 2020and 2023, A consortium of 11 institutions from 4 countries in Africa and 3 countries in Europe created a consortium to contribute to better, more accessible, and more efficient health and care services in LLMICs in Africa, by coordinating and supporting the deployment of eHealth. The project received a grant from EC H2020 grant scheme to be implemented from 2020-2023. USN was part of the consortium through Dr. Shegaw Anagaw Mengiste as he worked as co-PI in the consortium. USN led the task of Strengthen the research capacity to inform eHealth policy in the four participating African LLMICs. USN led the task to map existing eHealth research groups and networks in the regional hubs and other African countries.

A qualitative online survey was developed by USN, UNN, UoO, GHS, JU and UoG. The survey aimed to identify the research agenda, priorities, and topics of interest in the eHealth research community in Africa. The survey was distributed through the Regional Hubs and partners network, targeting researchers from African universities, institutions, and organizations.
The survey got 18 respondents from Ghana, Tunisia, Malawi and Ethiopia. The analysis showed that the eHealth research communities in Ethiopia, Ghana, Malawi and Tunisia focus on health

information management systems, but have limited attention to policies and varying attention to IT skills of healthcare workers.

The survey findings were utilized to provide a comprehensive report on the status of eHealth research in Africa for the BeH project (D2.6). The research paper "Research Landscape and Research Priorities in eHealth in four African Countries - A survey" was presented at the EGOVCeDEM-ePart 2022 conference, and published in the conference proceedings. Because of the low recruitment in the survey, the task members decided to use a systematic review method. We widened the scope of the review (due to limited findings related to research priorities) to include policy frameworks. The findings of the systematic review are published at BMC Health Services Research with the title "eHealth Policy Framework in Low and Lower Middle-Income Countries; A PRISMA Systematic Review and Analysis".

USN also led the establishment of four regional hubs in the four BeH project countries (Ethiopia, Ghana, Malawi, and Tunisia). Each hub has organized their own regional workshop during the two first years of the BeH project. In the six-month extension period, the regional hubs were paired to organize two joint regional workshops. The regional workshops have been organized both in virtual and hybrid format. The first international workshop took place in M12 as a digital event, and the second international workshop occurred in M23 as part of the Africa Telehealth Conference (https://www.africa-telehealth.com). We have also created an online community (https://community.betterehealth.eu). The activities of the community will be hosted on a new platform coordinated by the BeH working group in the International Society for Telemedicine and eHealth (ISfTeH). A series of webinars has been arranged in the two last years of the BeH project

- Key researcher: Shegaw Anagaw Mengiste, Associate Professor in IT at Department of History, Sociology and Busines, USN.

3. References to the research (indicative maximum of six references)

Selected references to key outputs from the research described in the previous section:

Seven scientific peer-reviewed papers have been published, and we work with more articles. Five popular science articles have been published. Dissemination and communication of BeH project results has remained a priority throughout the period of the BeH project.

The papers are:

1. Strategic Partnerships in e-Health in Low and Lower Middle-Income Countries in Africa. Rayhane Koubaa; Sana Rekik; Mohamed Jmaiel; Million Tesfaye; Maame Esi Amekudzi; Muyepa Anthony; Moges Asressie; Konstantinos Antypas. 2022, **IST-Africa Conference (IST-Africa).**
2. Assessing Strategic Priority Factors in eHealth Policies of Four African Countries, Dillys Larbi; Kirsti Sarheim Anthun; Flora Nah Asah; Oksana Debrah; Konstantinos Antypas, 2022 **IST-Africa Conference (IST-Africa).**
3. Obstacles to eHealth Capacity Building and Innovation Promotion Initiative in African Countries. Flora Nah Asah, Jens Johan Kaasbøll, Kirsti Sarheim Anthun. pHealth 2022.
4. Research Landscape and Research Priorities in eHealth in four African Countries -A survey. **Shegaw Anagaw Mengiste**, Konstantinos Antypas, Marius Rohde Johannessen, Jarn Klein, Gholamhossein Kazemi, Jens Kassbøll. **EGOV-CeDEMePart 2022.**

5. eHealth Policy Framework in Low and Lower Middle-Income Countries; A PRISMA Systematic Review and Analysis. **Shegaw Anagaw Mengiste**, Konstantinos Antypas, Marius Rohde Johannessen, Jarn Klein, Gholamhossein Kazemi. **BMC health services research.**
6. 6. Facilitators and Barriers to the Sustainability of eHealth Solutions in Low- and Middle-Income Countries: Descriptive Exploratory Study. Adane Mamuye, Araya Mesfin Nigatu, Moges Asressie Chanyalew, Lamia Ben Amor, Sihem Loukil, Chris Moyo, Samuel Quarshie, Konstantinos Antypas, Binyam Tilahun. **JMIR Formative Research**.

4. Details of the impact (indicative maximum 750 words)

An overview of the performance of BeH compared with the indicators and targets presented as follows:

- Higher level of international cooperation and networking in eHealth programs and policies between European countries or regions and low and middle income African countries, focusing on areas that are beneficial to the target countries / regions and their citizens in eHealth. The main activity of the project was to create registries of eHealth solutions and eHealth policies. Due to the high research and analytical competence of our partners, we were able to analyse to produce these registries to identify areas that are more beneficial to the citizens of the participating LLMICs in the region they have the responsibility for. These areas were the main focus for the cooperation and networking efforts with authorities and professionals in all regions of Africa. Besides, BeH has developed collaboration with the Africa HealthTech Hub and IAPO. In addition, we have facilitated cooperation between the Africa HealthTech Hub and the Africa Digital Health Summit in 2023.
- BeH developed eHealth policy roadmap that identified 25 focus areas that eHealth policies and programs for LLMICs need to address. Those policy roadmaps cover the following areas: leadership and governance, strategy and investment, services and applications, infrastructure, standards and interoperability, legislation, policy and compliance, and workforce (as categorized by the National eHealth Strategy Toolkit of WHO and ITU).
- The project addressed several human, technical and policy related factors that can increase the opportunities for eHealth innovators. As part of addressing human related factors, we identify and connect with capacity building initiatives that will increase the number of eHealth innovators and provide them with the necessary skills. As part of our activities related to the technical factors, we identified requirements and promote solutions for sustainable infrastructure, that will allow eHealth innovators to provide advanced and reliable eHealth solutions. BeH also contributed to standardization and interoperability initiatives that will increase the opportunities of eHealth innovators to build complementing services. Such initiatives will also increase productivity and reduce costs for eHealth innovators.
- As part of the activities related to the human factors, our project contributed in empowering patients and citizens to participate in the formulation of eHealth policies and programmes. Wel also identified and connect with initiatives that aim at increasing digital literacy and facilitating the wider use of eHealth. As access to health and eHealth services has both socioeconomic and gender dimensions, the project's activities will identify, connect with, and support relevant initiatives that address these dimensions. Another aspect that has been addressed in the project and will increase opportunities for patients was the improved user friendliness and accessibility of eHealth. As the project identified and promote existing initiatives for user friendly and accessible eHealth solutions, more citizens will have the opportunity to use them regardless of gender, age, or disabilities.

- BeH developed eHealth registry system in all regional hub countries that helped to register existing eHealth solutions with relevant documentation of their effect. This system helps health professionals make informed decisions regarding the use of eHealth solutions. Our experience has showed that systematic and summarised evidence has the potential to increase the use of e health among health professionals.
- BeH also contributed to improve accessibility of eHealth services by connecting and supporting capacity building initiatives for health professionals. In this way, more professionals were able to use eHealth, and to provide eHealth services to their patients. In parallel, through connecting and contributing to activities related to improving user-friendliness and universal access, eHealth will become easier to access by more users. We also connect with initiatives that are addressing digital literacy, since low literacy hinders users from benefiting from eHealth services.
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4. Sources to corroborate the impact (indicative maximum of ten references)

The following are links to corroborate the impact of our project:

- The eHealth registry: is an open, free and easy to access registry with information about eHealth solutions and eHealth policies in African countries. The Registry | BettereHealth.eu
- Events: The BETTEReHEALTH project will also organize multiple international networking events and regional workshops. On this page we added a list of all events where you can meet us. Events | BettereHealth.eu
- Regional Hubs: BETTEReHEALTH established four Regional eHealth Hubs across Africa, led by a local partner of the BETTEReHEALTH consortium, and already endorsed by their national Ministry of Health. Join our Regional Hubs | BettereHealth.eu
- International cooperation and community engagement: BeH contributed to increased the level of international cooperation in eHealth, inform and strengthen end-user communities and policy makers in making the right decisions for the successful implementation of eHealth, and lead to increased opportunities for stakeholders in Africa and Europe with the overall aim of better health outcomes through better healthcare accessibility and higher quality. Project | BettereHealth.eu
- News and Updates: a list of news and updateds on our project activities can be found in this link: News and Updates | BettereHealth.eu

University of South-Eastern Norway, USN School of Business [2]

Institution: University of South-Eastern Norway
Administrative unit: USN School of Business
Title of case study: Entrepreneurial Software Engineering: Bridging the Gap between Engineering and Business in Startups
Period when the underpinning research was undertaken: 2017-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2017-2022
Period when the impact occurred:2017-2022

1. Summary of the impact (indicative maximum 100 words)

This research examines the application and adaptation of software development methodologies with entrepreneurial strategies in a startup context. It highlights how integrating these disciplines enhances innovation, accelerates productive product development, and embrace startup-driven engineering approaches. The study's impact lies in providing actionable insights for startup founders and software engineers, leading to more efficient ways of developing software products in startups. It underscores the importance of interdisciplinary approaches in the fast-paced startup world, offering guidance on balancing technical excellence with entrepreneurial agility for sustainable growth and competitiveness in the high-tech industry.

2. Underpinning research (indicative maximum 500 words)

Between 2017 and 2022, Dr. Anh Nguyen-Duc has actively conducted empirical research on an interdisciplinary research on software startups, building upon his previous work at NTNU (2015-2017). The work is also a result of a long-term collaboration among European and international research groups on the topic. The Software Startups Global Research Network (https://softwarestartup.org/), comprising 55 members from different countries, has contributed over 130 peer-reviewed articles published in esteemed journals and conferences across Software Engineering, Information Systems, Engineering Management, and Entrepreneurship. Dr. Nguyen-Duc's work in the startup context bridges traditional software development practices with entrepreneurial dynamics. Software product development in startup context is found to be a unique phenomenon that combines both established way of developing software and influences of entrepreneurial logics. Dr Anh Nguyen-Duc has proposed and evaluated a number of methods and techniques for software development activities in startup context, for example an MVP model, entrepreneurial logic of startup software development, and StatCard. On one hand, our body of empirical insights on startups inform and call for updates of existing software development approaches to integrate co-creation, resilience, agility and efficiency into new software development context. On the other hand, our research implies many lightweight approaches and best practices for startup practitioners.

- Key researcher: Anh Nguyen-Duc, Professor in IT at Department of Economics and IT, USN

0. References to the research (indicative maximum of six references) Selected references to key outputs from the research described in the previous section:

1. Hooshyar, H., Guerra, E., Melegati, J., Khanna, D., Aldaeej, A., Matturro, G., Zaina, L., Greer, D., Rafiq, U., Chanin, R., Wang, X., Garbajosa, J., Abrahamsson, P., Khomh, F., & **Nguyen-Duc, A**. (2023). Impact in Software Engineering Activities After One Year of COVID-19 Restrictions for Startups and Established Companies. IEEE Access, 11, 55178–55203. https://doi.org/10.1109/ACCESS.2023.3279917

2. Kemell, K.-K., **Nguyen-Duc, A.**, Suoranta, M., & Abrahamsson, P. (2023). StartCards—A method for early-stage software startups. Information and Software Technology, 160, 107224. https://doi.org/10.1016/j.infsof.2023.107224
3. **Nguyen-Duc, A.,** Kemell, K.-K., & Abrahamsson, P. (2021). The entrepreneurial logic of startup software development: A study of 40 software startups. Empirical Software Engineering, 26(5), 91. https://doi.org/10.1007/s10664-021-09987-z
4. Berg, V., Birkeland, J., **Nguyen-Duc, A.,** Pappas, I. O., & Jaccheri, L. (2020). Achieving agility and quality in product development—An empirical study of hardware startups. Journal of Systems and Software, 167, 110599. https://doi.org/10.1016/j.jss.2020.110599
5. Berg, V., Birkeland, J., **Nguyen-Duc, A.,** Pappas, I. O., & Jaccheri, L. (2018). Software startup engineering: A systematic mapping study. Journal of Systems and Software, 144, 255–274. https://doi.org/10.1016/j.jss.2018.06.043

4. Details of the impact (indicative maximum 750 words)

The Research Underpinned the Impact in several ways:

- Dissemination and Influence: The research findings were disseminated through over 30 peer-reviewed articles in recognized journals and conferences in Software Engineering and Engineering Management. Most of the research is made available under open science movement. This widespread and distribution facilitated the research's influence on a global scale, reaching a diverse audience that includes academics, practitioners, and startup entrepreneurs.
- Integration of Research in Practice: The methods and techniques proposed by Dr. Nguyen-Duc, such as the MVP model and entrepreneurial logic in software development, were directly applied in startup environments. These practical applications include training and coaching for startup companies, teaching students at both engineering and business programs at different universities (USN, NTNU, UiO, Oslomet, etc)
- Collaboration and Contribution: Dr. Nguyen-Duc's research was a part of a broader collaboration with the Software Startups Global Research Network. The work under collaboration among network members and also disseminated through the network. The collaboration enhanced the scope and depth of the research, but Dr. Nguyen-Duc's work stood out for its practical relevance and direct application in startup contexts

Nature and Extent of the Impact

- Empirical Research on Software Development: The research has contributed to a paradigm shift in traditional software development practices, integrating aspects like resilience, agility, and co-creation. This shift has not only benefitted startups but also larger organizations looking to innovate their software development processes.
- Educational Impact: The research has been instrumental in shaping the curriculum and teaching methods in software engineering and entrepreneurship courses. Educational institutions have adopted the research findings to prepare students for the unique challenges of startup environments.
- Practical Impact: Startups globally have benefitted from the research by adopting the proposed methods and techniques, leading to more efficient and agile development processes. This transformation has enabled startups to better navigate the complexities of software development while embracing entrepreneurial dynamics.

5. Sources to corroborate the impact (indicative maximum of ten references)

Link: https://softwarestartup.org/

Our mission is disseminating novel research findings in the context of software startup and informing entrepreneurs with necessary knowledge, tools and methods to minimise threats and maximise chances of successes. The network have 50 active members who contribute and meet in a regular basic We have ca. 3000+ unique visitors to the website during its operational time.

https://bia.unibz.it/esploro/outputs/conferenceProceeding/Software-Startup-Education-Around-the-World/991006186595301241 https://www.e-informatyka.pl/attach/e-Informatica_-_Volume_10/eInformatica2016Art5.pdf
https://resetworkshop.org/pdf-programs/
https://dsd-seaa2017.ocg.at/se4su2017.html
https://www.ba.lv/info/product-development-methods-and-process-management-in-ict-companies-with-high-growth-potential-and-opportunities-to-use-their-experience-in-start-up-companies-of-a-similar-profile-in-latvia/

Østfold University College, Faculty of Computer Science, Engineering and Economics

Case 1, Gjellestad ship

Institution: Østfold University College
Administrative unit: Faculty of Computer Science, Engineering and Economics
Title of case study: Gjellestad ship
Period when the underpinning research was undertaken: 2019 -2020
Period when staff involved in the underpinning research were employed by the submitting institution: 2018 -
Period when the impact occurred: 2019 - today

1. Summary of the impact

The research and findings surrounding the Gjellestad ship in Norway represent a significant advancement in the field of archaeology and history, particularly in the study and preservation of Viking heritage. The challenge of effectively conveying Cultural Heritage (CH) transcends traditional disciplines, encompassing not only archaeologists, historians, and curators, but also including unique skills of designers and developers crafting virtual reality environments. The innovative combination of 3D models, simulations, and a diverse array of interfaces including web, desktop, mobile, virtual reality (VR), and augmented reality (AR) have great impact both as scientific tools for historians, and for creating public interest and understanding.

2. Underpinning research

In 2018, Østfold County Council discovered the Gjellestad ship at Vikssletta outside Halden using a ground-penetrating radar. The find garnered significant interest, but there was nothing to see. Therefore, the researchers took the initiative to bring the discovery to life digitally. Østfold University College, Østfold County Council, the Institute for Energy Technology, and Nordic Media Lab started a R&D collaboration on this in early 2019. In the fall of 2019, they worked on assembling a digital model of Gjellestad based on all available knowledge at that time, and the needs of the historians and archeologists. The goal was to create tools for interpretive scientific work and also how this work would be presented and made interesting for a broad audience. Early in 2020, the group launched the Gjellestadstory.no.

The work done by ØUC comprises technology and expertise gained over several years in the research group. Thus, in this project, most of our work was on the development side of R&D. Our deliveries made it possible for the archeologists and historians to get better and new insight that would not have been possible without ØUC. Thus, the complete project demonstrated new options for archeological research to gain new knowledge.

Remark: We acknowledge that this impact case is not based upon specific research results, derived in the project or in directly preceding activities. Still, our expertise contribution, including our multidisciplinary research experience, made archeologic research and insight advance in this multidisciplinary endeavour. The research activities at ØUC are relatively young, meaning that we do not have many cases where our own research has had time to mature and develop into impact cases.

- Names of the key researchers and what positions they held at the administrative unit at the time of the research (where researchers joined or left the administrative unit during this time, these dates must also be stated).

Joakim Karlsen, Associate Professor, Department of Computer Science and Communication.

3. References to the research

- Author(s): Karlsen, Joakim; Havgar, Margrethe & Rødsrud, Christian Løchsen
- Title: 'Always Viking': Archaeologists Collaborating with Public Service Media to Broaden Access to Archaeological Fieldwork
- Year of publication: 2023
- Type of output and other relevant details required to identify the output: 10.1080/14655187.2023.2213511

0. Details of the impact

Digital cultural heritage archives often serve as repositories for static and underutilized digital assets. These repositories struggle to engage active and collaborative efforts in interpreting and understanding their contents, particularly when artifacts are inaccessible due to destruction or being buried underground or underwater. While the creation of virtual experiences to make these sites accessible is a growing trend, it faces challenges such as the scientific conjecture involved in creating these experiences and the hesitation of cultural institutions to fill data gaps to create comprehensive experiences.

Archaeological institutions, especially within Europe, are diligently working to digitize and manage cultural heritage data. For decades, these institutions have endeavored to extract value from digitization processes through initiatives aimed at enhancing capture, storage, management, analysis, and dissemination of archaeological data. This effort contributes to a broader infrastructure supporting cultural heritage data at regional, national, and European levels. This infrastructure is underpinned by a political rationale emphasizing the importance of preserving cultural heritage assets for future generations. Through these processes, a significant volume of data has been made accessible, benefiting cultural partners, creative professionals, and audiences with an interest in historical remains and their narratives. The ongoing digitization process seeks to break down barriers to value creation in scientific, economic, and cultural realms.

The case of gjellestadstory.no demonstrates challenges in handling veracity and incorporating new data in a static and somewhat unsustainable manner. Implementing a dynamic visualization of Gjellestad, which evolves with ongoing excavation findings, would enhance the user experience, create opportunities for creative professionals, pique the interest of archaeological institutions, and reduce physical strain on the archaeological site.

"Gjellestad Story" offers a digital journey through various historical periods of the Gjellestad site in Norway. Beginning with an animated video of Viking ships on turbulent seas, it sets an immersive tone. The experience provides a bird's-eye view of an evolving landscape over centuries, highlighting the development of structures and burial mounds, and giving insights into various historical epochs, societal conflicts, and elite burials. The platform does more than showcase a Viking ship; it narrates the site's history from the Bronze Age to the present, enriched with informative videos and texts. A key feature is the 3D representation of the Gjellestad Ship, offering

multi-perspective explorations and is an engaging and immersive portal into the Viking age and archaeological discoveries. In its first year, the website attracted 215,000 unique visitors. Of these, approximately 50,000 delved deeper into the presentations, while the fly-through videos garnered about 100,000 views. The visualization has also been shared and utilized by global news and magazine editors, including BBC (UK), NHK (Japan), ZED (France), Historia (France), Newsflash (UK), INTERSPOT (Austria), BILD (Germany), Le Monde (France), and National Geographic.

5. Sources to corroborate the impact

1. Gjellestadstory.no
2. Department of Scandinavian Studies at University of Washington made a podcast with Karlsen about the project and the findings. (Episode 24)
3. The national Nordic museum in Seattle recently hosted a webinar with Karlsen and colleagues. (Youtube)
4. Gjellestad findings alive online. (Arkivsak hiof.no)

Østfold University College, Faculty of Computer Science, Engineering and Economics
Impact Case 2. Greener and more sustainable buildings

Institution: Østfold University College

Administrative unit: Faculty of Computer Science, Engineering and Economics
Title of case study: Greener and more sustainable buildings
Period when the underpinning research was undertaken: 2015-

Period when staff involved in the underpinning research were employed by the submitting institution: 2012-

Period when the impact occurred: 2020-

1. Summary of the impact

The impact of this study is new knowledge and increased commercial interest regarding green solutions for more sustainable buildings. Specially regarding utilization phase change materials which can be used to make buildings more energy efficient, geopolymers for making more environmentally friendly concrete, and utilization of life cycle assessment (LCA) to quantify the sustainability of materials and buildings. We have also developed methods for teaching students how to improve the sustainability of buildings by utilization of LCA in combination with building information modeling (BIM). In addition, we have utilized LCA in the process of helping large number of businesses develop green business models.

2. Underpinning research

The case study started with the project "Micro-encapsulated phase change materials in concrete" funded by RCN (2015-2019). This project included 4 PhDs, two of which are now employed as Associate Professors at HIOF. That project resulted in new knowledge regarding how we can utilize phase change materials (PCM) to improve the energy efficiency of buildings. During the project we also built expertise regarding geopolymers, which can be used to make concrete that is much more environmentally friendly than ordinary Portland cement.
Based on our geopolymer research, we were contacted by the European Space Agency (ESA), and conducted a project together with them regarding "Optimizing geopolymer recipe for lunar 3D printing" (2018-2021). This further increased our knowledge regarding geopolymers, and we discovered that urea can be used to reduce the water needed to make geopolymers on the moon.

Our experience with green and sustainable buildings was then further utilized and extended in the Greenbizz project (2020-2022), where our consortium worked to help 60 different companies develop green business models. In Greenbizz HIOF also employed 2 PhD students (still in progress). This project helped us develop skills in LCA (life cycle assessment), which is very important for checking which solutions are most sustainable. Included in these 60 businesses, there were several that were directly relevant for the development of green and sustainable buildings.

The LCA competence was then further utilized in the Erasmus+ project BIM-LCA construction (2022-2024), focusing on developing methods to teach students how to use LCA in combination with BIM (building information modeling) to achieve more energy efficient and sustainable buildings.

We have recently started up a new Horizon Project called SNUG (2023-2027), where the aim is to maximize the energy efficiency of buildings, while minimizing greenhouse gas emissions throughout its life cycle (design, construction, renovation, operation and end of life), at a cost optimal level, combined with a comfortable and healthy indoor climate. Our contribution to this Horizon project includes developing self-leveling concrete containing PCM. In addition, we are responsible for the LCA of the whole project, and for training activities for students. This project is at a high TRL level, and we are going all the way to test the developed materials in real building and check both for how efficient they are in real-life situations and for user satisfaction.

The case study research has resulted in 23 publications registered in ISI Web of Science.

The project team:
Anna-Lena Kjøniksen, (Professor)
Vinh Duy Cao (PhD student)
Shima Pilehvar (PhD-student, later Associate Professor)
Susana Garcia Sanfelix (PhD-student, later Associate Professor)
Anna Szczotok (PhD student)
Bjørn Gitle Hauge (Assistant Professor)
Lars Tellnes (PhD student)

3. References to the research

- Vinh Duy Cao, Shima Pilehvar, Carlos Salas-Bringas, Anna M. Szczotok, Juan F. Rodriguez, Manuel Carmona, Nodar Al-Manasir, Anna-Lena Kjøniksen
  Microencapsulated Phase Change Materials for Enhancing the Thermal Performance of Portland Cement Concrete and Geopolymer Concrete for Passive Building Applications
  Energy Conversion and Management, (2017), 133, 56-66.
- Shima Pilehvar, Vinh Duy Cao, Anna M. Szczotok, Luca Valentini, Davide Salvioni, Matteo Magistri, Ramón Pamies, Anna-Lena Kjøniksen
  Mechanical Properties and Microscale Changes of Geopolymer Concrete and Portland Cement Concrete Containing Micro-Encapsulated Phase Change Materials.
  Cement and Concrete Research (2017), 100, 341-349.
- Vinh Duy Cao, Shima Pilehvar, Carlos Salas-Bringas, Anna M. Szczotok, Luca Valentini, Manuel Carmona, Juan F. Rodriguez, Anna-Lena Kjøniksen
  Influence of Microcapsule Size and Shell Polarity on Thermal and Mechanical Properties of Thermoregulating Geopolymer Concrete for Passive Building Applications.
  Energy Conversion and Management, (2018), 164, 198–209.
- Shima Pilehvar, Anna M. Szczotok, Juan Francisco Rodriguez, Luca Valentini, Marcos Lanzón, Ramón Pamies, Anna-Lena Kjøniksen
  Effect of Freeze-Thaw Cycles on the Mechanical Behavior of Geopolymer Concrete and Portland Cement Concrete Containing Micro-Encapsulated Phase Change Materials. Construction and Building Materials, (2019), 200, 94-103.
- Shima Pilehvar, Marlies Arnhof, Ramón Pamies, Luca Valentini, Anna-Lena Kjøniksen
  Utilization of Urea as an Accessible Superplasticizer on the Moon for Lunar Geopolymer Mixtures
  Journal of Cleaner Production, (2020), 247, 119177.
- Susana G. Sanfelix, Jesus D. Zea-Garcia, Diana Londono-Zuluaga, Isabel Santacruz, Angeles G. De la Torre, Anna-Lena Kjøniksen
  Hydration development and thermal performance of calcium sulphoaluminate cements containing microencapsulated phase change materials.
  Cement and Concrete Research, (2020), 132, 106039.

4. Details of the impact

Micro-encapsulated phase change materials (MPCM) can be added to concrete to increase thermal comfort and decrease energy consumption for heating and cooling. Some of the problems when adding MPCM to concrete are reduced strength of the concrete and much poorer workability of the pre-set concrete. We discovered that the reduced strength of the concrete was caused by a combination of poor mechanical strength of the microcapsules, weak interactions and airgaps between the microcapsules and the rest of the concrete matrix, and that addition of microcapsules causes poorer flow properties of the preset concrete which results in the formation of more air bubbles in the concrete. We found that we could reduce these problems by adding superplasticizers to improve flow properties and reduce air bubbles. In addition, we were able to adjust the shell of the microcapsules to reduce the adverse effects they have on the concrete properties. Utilizing of geopolymers instead of Portland cement was found to give better concrete properties when used in combination with MPCM. In addition, the geopolymers has the advantage of significantly reducing the CO_2-emissions of the concrete. We managed to develop concrete/MPCM recipes that according to our computer simulations could reduce energy consumption needed for heating and cooling a building by up to 30 % while maintaining sufficient strength for construction purposes. As an extra advantage, these concrete recipes showed better frost resistance than corresponding concrete without MPCM. We also discovered that MPCM can cause problems with poorer fire resistance of the concrete, illustrating that paraffin waxes might not be the best option for PCM materials for building applications.

For construction of buildings on the moon it is essential to utilize materials that can be found on the moon itself, as brining in materials from earth is extremely expensive and requires huge amounts of energy. We found that lunar regolith can be used to make geopolymers for construction on the moon adding only water (of which there is some but not much available on the moon), NaOH (which can be made from components available on the moon), and urea. Our main discovery was that urea (which can be extracted from urine) can be used to reduce the amount of water needed by about 32 %. Basalt fibres (can also be made on the moon) can be used to increase the strength of the Lunar regolith geopolymers.

One of the challenges when aiming at reducing the adverse environmental impact of a business is to find which measures gives the best cost/benefit effect. In the Greenbizz project, we were helping SMEs (small and medium sized enterprises) with this by utilizing LCA to quantify CO_2-equ. emissions from different parts of their activities and products. We found that some of the challenges with this process is to obtain enough information from the SME to be able to conduct a LCA analysis, and to decide how detailed the LCA should be (too detailed requires a lot of time and a lot of information from the SME, too few details risk reducing the accuracy of the analysis so much that the results cannot be trusted). We found that for the building industry, economic initiatives can help the transition toward low-emission buildings. A screening of some initiatives showed that better loans for green rehabilitation that can result in buildings with 30 % lower energy use.

Through our BIM-LCA construction project, we have developed teaching materials and teaching processes to help teach students about LCA and BIM, and how to utilize these tools to construct buildings with a lower environmental impact (both during the construction phase and use of the building). Since these students are the future actors in the building industry, their competence in this area is essential for achieving the green transition.

5. Sources to corroborate the impact

Examples of conference presentations:

- *The Effect of Micro-encapsulated Phase Change Materials in Liquid State on Properties of Geopolymer and Portland Cement Concrete*
  International Conference on Energy, Environment and Economics, Edinburgh, 2016
- *The Effect of Microcapsulated Phase Change Materials on Thermal and Mechanical properties of Geopolymer Concrete*
  Advanced Building Skins Conference, Bern, 2017
- *Rheological performance of cement composites with Microencapsulated Phase Change Materials*
  3rd International Conference of Innovative Materials, Structures and Technologies, Riga, 2017
- *Development of thermoregulating microcapsules having flame retardant properties for building applications*
  3rd International Conference of Innovative Materials, Structures and Technologies, Riga, 2017
- *Building a Base on the Moon? New Research in Regolith Concrete*
  Spaceport Norway 2019, Trondheim, 2019

Examples of media appearances:

- Hus og jordbruk på månen, Lørdagsevyen, NRK, 14/11-2020
  https://tv.nrk.no/serie/dagsrevyen/202011/NNFA02111420/avspiller
- Astronaut urine for building a Moon base, Science & Exploration, 2020
  https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Astronaut_urine_for_building_a_Moon_base
- On the Moon, Astronaut Pee Will Be a Hot Commodity, Weird, 2020
  https://www.wired.com/story/on-the-moon-astronaut-pee-will-be-a-hot-commodity/
- Hva er månebetong?, Abels tårn, 6/10-2023
  https://radio.nrk.no/serie/abels-taarn-radio/sesong/202310/MDFP05007923

High media impact on Altmetric:

- *Utilization of urea as an accessible superplasticizer on the moon for lunar geopolymer mixtures:*
  "This research output has an Altmetric Attention Score of 1707. This is our high-level measure of the quality and quantity of online attention that it has received. Altmetric has tracked 25,255,356 research outputs across all sources so far. Compared to these this one has done particularly well and is in the 99th percentile: it's in the top 5% of all research outputs ever tracked by Altmetric."
  https://www.altmetric.com/details/69874810#score

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