ANNUAL REPORT

2021

HydroCen

NORWEGIAN RESEARCH CENTRE FOR HYDROPOWER TECHNOLOGY

CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

HydroCen is a research centre for environmentally friendly energy. Our main objective is to enable hydropower to meet complex challenges and exploit new opportunities through innovative technological solutions.

The main research partners in HydroCen are The Norwegian University of Science and Technology (NTNU), SINTEF Energy Research and Norwegian institute for nature research (NINA). The centre has a total budget of 400 million NOK over eight years and is financed by the Norwegian Research Council (50%), the research institutions (25%) and partners from the hydropower industry (25%).

WP 1 Hydropower structures

WP 2 Turbine and generator

WP 3 Market and services

WP 4 Environmental design

2021: FIVE YEARS PASSED – THREE YEARS TO GO

Liv Randi Hultgreen

HydroCen has been delivering world-leading research for five years, and hydropower has without a doubt become more relevant in the eye of the public. The coming challenges within hydropower production related to a full-scale electrified and renewable community get much attention. We welcome the rising engagement and plan to spend the next three years to provide solutions. Please take the time to update yourself on our achievements and join me in applauding our great staff of scientists!

In 2021, HydroCen underwent a thorough evaluation under the auspices of the Norwegian Research Council, carried out by an expert panel of independent professionals. This evaluation proved to be a good opportunity to review and adjust the centre's goals and strategies, in line with the industry's needs. The centre passed the evaluation with flying colours and was approved funding for another three years of research. Although this didn't come as surprise, we were all very pleased to get such good feedback from the evaluation panel and to get funding for another three years.

In 2021 HydroCen's project portfolio was expanded with 22 new projects, the Open Calls projects. These projects were a valuable expansion involving research subjects that deserved more focus, and more information on each project is available in this report. They have a wide variety in size, timeline and subject, and they are all anchored in HydroCen's goals and strategy. We have also launched the project Kunnskapsbanken, a knowledge hub where all our research results will be communicated in the coming years.

23 PhDs and Postdocs have been funded by HydroCen this year, and 26 Master students have completed their thesis'. The research activity has been high, with several successful field tests, resulting in high quality scientific publications and several conference presentations. Five PhDs completed and defended their thesis' in 2021, and they all had a job waiting within hydropower industry after completion.

In 2021 we have seen several results materialize, as activity picked up speed again after covid-lockdown. The research on fault detection in generators have matured further, towards implementation of solutions for machine detection and learning within predictive maintenance. The work on new tools and solutions for tunnel surveillance has also materialise, giving us better tools to predict tunnel lifetime.

I recommend that you read up on the research highlighted in this report and encourage you to reach out to our scientists if you would like more information.

International cooperation is key for hydropower research, and we are involved in many high-quality research activities. We are part of projects in the USA, Canada, Nepal, India, Brazil and Europe, either through HydroCen-funded projects or associated projects.

In 2022 we will initiate 11 new projects, which will focus on the implications from more dynamic operational modes for equipment, tunnels, rivers, reservoirs, and fish. six new PhDs and Postdocs will start their research, in close cooperation with our industry partners.

FME HydroCen's success lies in the hands of our world-leading scientists, our engaged and interested user partners, our ever-supportive board and leadership team. On behalf of the administration, I would like to thank you all!

Liv Randi Hultgreen,
Executive Director, HydroCen

Bibek Neupane has developed a new method that can be used to monitor the rock mass pore pressure changes in hydropower tunnels, which may occur during load changes in the powerplant.

Power plants with block fall problems can use this method in their tunnels in real time, to decide on a suitable valve opening/closing time in order to delay the possible rock mass fatigue. This is a highly relevant issue as more intermittent energy sources have become a significant part of the energy system, causing frequent load changes and hence, increased strain on hydropower operations. It is likely that frequent start-stop of production can increase the strain on tunnel systems and cause more need for maintenance and monitoring.

This new method can be helpful in reducing hydraulic stresses on rock masses around tunnel and reducing block fall events as result.

After finishing his work in HydroCen Neupane joins Rambøll in Trondheim as an engineering geologist.

Doctoral thesis by Bibek Neupane: Long-term impact on unlined tunnels of hydropower plants due to frequent start/stop sequences: https://hdl.handle.net/11250/2979204

Photo: Juliet Landrø/HydroCen

Livia Pitorac studied the possibility of upgrading hydropower plants to pumped storage plants, a solution that can provide both short term and long-term energy storage to the power market. The study highlights hydraulic design challenges that an upgrade can encounter, as well as proposes mitigation solutions in terms of the tunnel system/surge tank design, such as expansion or modification into a differential surge tank. The results of the study enables converting of hydropower to pump storage projects in cases with multiple surge tanks and brook intakes and shows the huge potential as a technical solution that can satisfy social, economic, and environmental requirements in Europe's energy system.

After finishing her Doctoral Thesis, Livia Pitorac started working as Project Manager/Flow Solutions Specialist at Flow Design Bureau AS.
Doctoral thesis by Livia Pitorac: Upgrading of Hydropower Plants to Pumped Storage Plants: Tunnel System Hydraulics:
https://hdl.handle.net/11250/2826677


Photo: Livia Pitorac/NTNU


Photo: Energiteknikk

DECISION ANALYTICS IN HYDROPOWER:

INVESTMENT AND OPERATIONAL PLANNING UNDER UNCERTAINTY

New insights and tools for decision support for operations and investments for owners of hydropower assets can contribute to more efficient operation of hydropower plants.

Many hydropower plants rely on old technology from the large-scale hydropower projects in the mid-20th century. In addition to an aging hydropower fleet, most of the economically viable hydropower potential in developed regions, is already exploited. Upgrading existing hydropower plants may therefore be more profitable than building new ones. To support decisions regarding renewal and upgrading projects of hydropower facilities, accurate and reliable mathematical models and methods are crucial.

Andreas Kleiven's thesis aims at imparting knowledge and develop optimisation models and methods for sustainable investment and operations in hydropower plants.

Hard to predict prices for the lifespan of hydropower projects
From a quantitative business analysis point of view, in a competitive market-based setting, owners of hydropower assets typically aim at finding a coordinated operations and investment schedule that maximises the market value of existing and potentially new assets. This includes the estimation of the inherent flexibility to dynamically take profit-maximizing decisions in response to arriving exogenous information, e.g., electricity prices and inflows to reservoirs.

Moreover, there are economic risks associated with undertaking large investment projects in hydropower, which are difficult to quantify. This is partly because the projects are irreversible and typically expected to last far beyond the horizon for which there exist electricity derivatives for controlling undesired risks.

Highlights from the thesis results:

- We demonstrate the real options perspective on maintenance activities, and we show that long-term electricity price expectations can be used as a basis for deciding when and which activity to choose. Overall, our analysis highlights the importance of having several performance-enhancing activities under consideration when prices are uncertain.
- Our results show that producers underestimate their marginal water value if the negative relationship between prices and resource availability is ignored. Nevertheless, the potential gain of incorporating co-movements between prices and resource availability when optimizing the operational policy is modest.
- We assess the performance of operational policies obtained from a heuristic that allows a straightforward integration of seasonal planning and intraweek scheduling and demonstrate how assumptions on within-week price variations affect investment policies.
- We provide a modeling framework and solution approach to support long-term investment decisions in hydropower plants focusing on downside risk. Our analysis shows that our approach may reduce the variability of the cashflow associated with an irreversible long-term investment.

Can be implemented by the industry
The aspects considered in this thesis provides useful insights and can be implemented by the industry. The researchers are hesitant in advising practitioners to explicitly model the relationship between local inflow, system hydrology and prices for optimizing the operational policy, given the modest profit gain. Furthermore, the thesis shows how short-term operational models and seasonal planning can be integrated and combined with long-term market price movements to evaluate investment alternatives. Finally, the thesis proposes a robust framework to support investment decisions. This framework focuses on downside risk and analyse different decision criteria for establishing investment policies under limited long-term information.

Overall, the analysis and results provide valuable insights and can be implemented and used by owners of hydropower assets.

Andreas Kleiven
HydroCen Phd

Decision analytics in hydropower: Investment and operational planning under uncertainty. Doctoral Thesis by Andreas Kleiven.

Photo: Juliet Landrø/HydroCen

EXPANDING ENVIRONMENTAL DESIGN

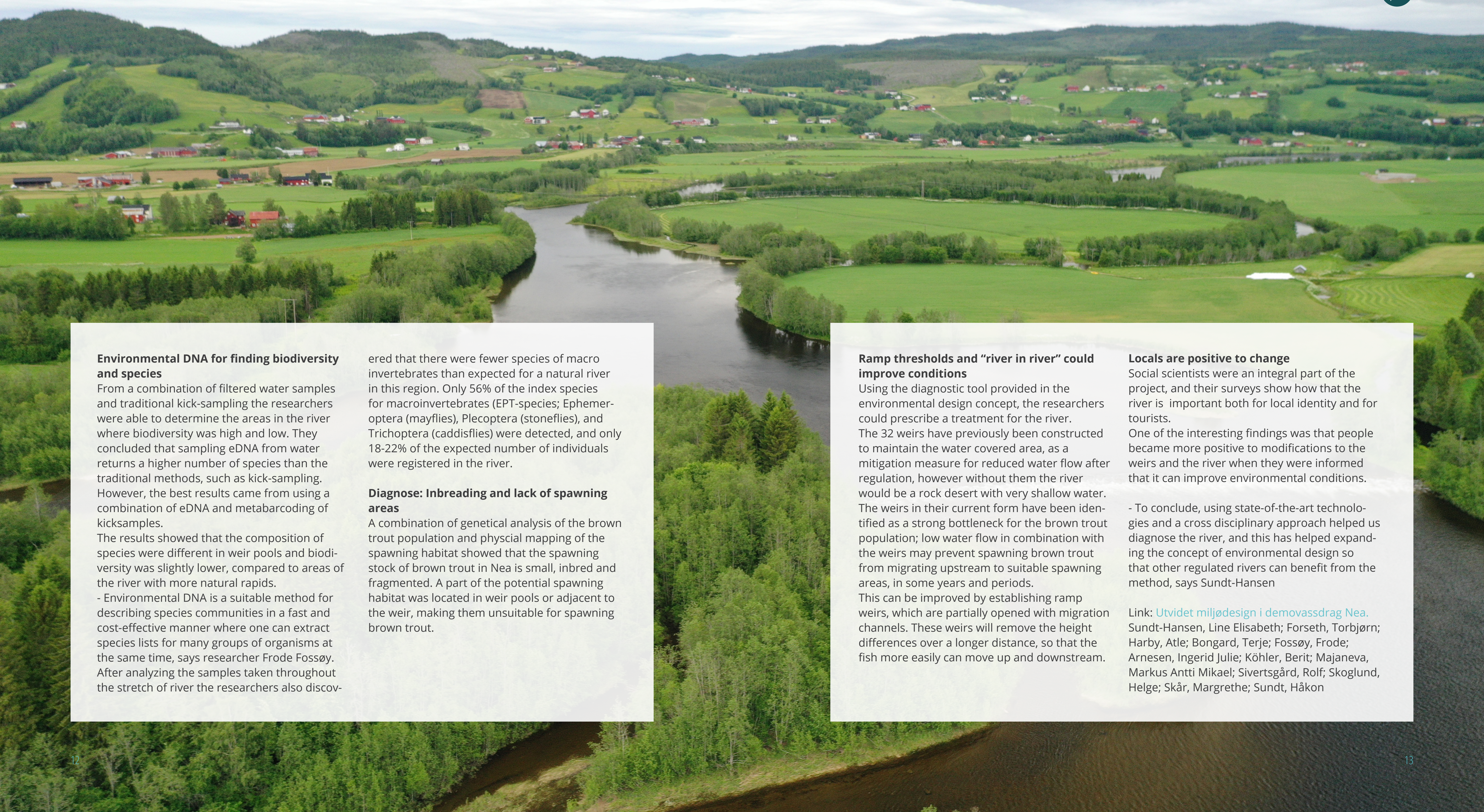
The results from the studies in the river Nea show that the use of environmental design can reach far beyond the realm of salmon. The report concludes that using state-of-the-art technologies and a cross disciplinary approach can successfully give advice to improve biodiversity and societal interests, while considering the hydro power production.

Extended toolbox
The researchers turned the local river Nea into a live laboratory to test various new tools for expanding the concept for environmental design, which was originally developed for salmon. River Nea is a typical inland watercourse where mainly brown trout and European minnow live, with some pike in downstream areas. The two latter fish species are non-native and have been perceived a risk to native fish species in Nea. This is also where Statkraft produces electricity. The river stretch which expands 33 km borders to farmland and wilderness and is used for recreational fishing and other recreational activities.
- Involving local interests has been a major part of the project, says Line Sundt-Hansen, who leads the work on environmental design in HydroCen.
She and her colleagues in HydroCen have also been a part of the research team who has used satellites, LIDAR, environmental DNA, advanced data modeling and surveys to create a holistic approach to environmental design.

Better and cheaper monitoring
By combining data from LIDAR, green laser can "see" under water and maps the riverbed, satellite images and aerial photographs, the HydroCen PhD-candidate Håkon Sundt has created a digital river model of Nea.
- Theere is a lack of flow conditions for many of the river stretches. By using remotely measured data, we can cost-effectively map rivers both in time and space, says Sundt.
Read more: Regionalised Linear Models for River Depth Retrieval Using 3-Band Multispectral Imagery and Green LIDAR Data (mdpi.com)

Environmental design aims to evaluate, develop, and implement measures to improve environmental conditions in regulated rivers, taking into consideration societal interests as well as hydropower production.

Originally developed for salmon in hydropower regulated rivers



Environmental DNA for finding biodiversity and species

From a combination of filtered water samples and traditional kick-sampling the researchers were able to determine the areas in the river where biodiversity was high and low. They concluded that sampling eDNA from water returns a higher number of species than the traditional methods, such as kick-sampling. However, the best results came from using a combination of eDNA and metabarcoding of kicksamples.

The results showed that the composition of species were different in weir pools and biodiversity was slightly lower, compared to areas of the river with more natural rapids.

- Environmental DNA is a suitable method for describing species communities in a fast and cost-effective manner where one can extract species lists for many groups of organisms at the same time, says researcher Frode Fossøy.

After analyzing the samples taken throughout the stretch of river the researchers also discovered that there were fewer species of macro invertebrates than expected for a natural river in this region. Only 56% of the index species for macroinvertebrates (EPT-species; Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) were detected, and only 18-22% of the expected number of individuals were registered in the river.

Diagnose: Inbreading and lack of spawning areas

A combination of genetical analysis of the brown trout population and physcial mapping of the spawning habitat showed that the spawning stock of brown trout in Nea is small, inbred and fragmented. A part of the potential spawning habitat was located in weir pools or adjacent to the weir, making them unsuitable for spawning brown trout.

Ramp thresholds and "river in river" could improve conditions

Using the diagnostic tool provided in the environmental design concept, the researchers could prescribe a treatment for the river.

The 32 weirs have previously been constructed to maintain the water covered area, as a mitigation measure for reduced water flow after regulation, however without them the river would be a rock desert with very shallow water.

The weirs in their current form have been identified as a strong bottleneck for the brown trout population; low water flow in combination with the weirs may prevent spawning brown trout from migrating upstream to suitable spawning areas, in some years and periods.

This can be improved by establishing ramp weirs, which are partially opened with migration channels. These weirs will remove the height differences over a longer distance, so that the fish more easily can move up and downstream.

Locals are positive to change

Social scientists were an integral part of the project, and their surveys show how that the river is important both for local identity and for tourists.

One of the interesting findings was that people became more positive to modifications to the weirs and the river when they were informed that it can improve environmental conditions.

- To conclude, using state-of-the-art technologies and a cross disciplinary approach helped us diagnose the river, and this has helped expanding the concept of environmental design so that other regulated rivers can benefit from the method, says Sundt-Hansen

Link: Utvidet miljødesign i demovassdrag Nea.
Sundt-Hansen, Line Elisabeth; Forseth, Torbjørn; Harby, Atle; Bongard, Terje; Fossøy, Frode; Arnesen, Ingerid Julie; Köhler, Berit; Majaneva, Markus Antti Mikael; Sivertsgård, Rolf; Skoglund, Helge; Skår, Margrethe; Sundt, Håkon

VORTEX GENERATORS CAN BE USED TO REDUCE STRUCTURAL VIBRATIONS

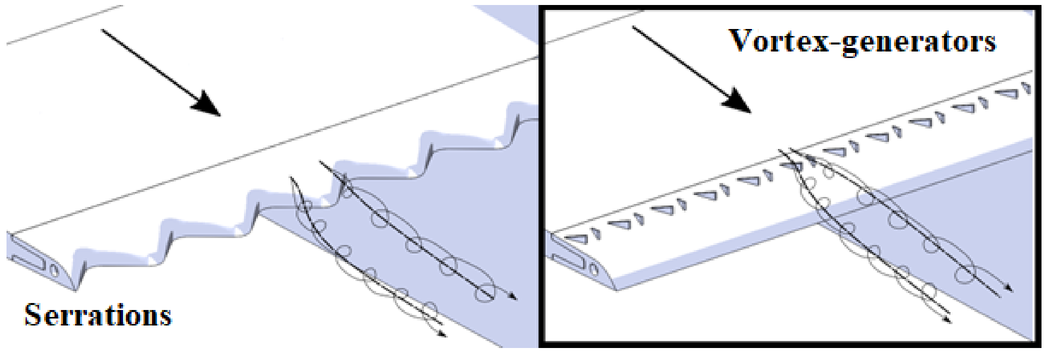
Kristian Sagmo

Pål Tore Storli

Project name:
Flow analysis and design methods for increased lifetime and operation of turbine components.

Duration:
2017-2021

Experiments suggest that semi-stable vortexes aligned with the flow can be used to dampen self-induced vibrations of machine component.



Figur 1: A (highly) simplified illustration of the streamwise vorticity introduced by the investigated designs.

Self-induced vibrations on blades or foils stemming from vortex shedding is a wide known problem encountered in multiple industries, in addition to the waterpower industry.
Within the waterpower industry this problem is perhaps most known to occur on stay-vanes, but may also occur on runner-blades and guide-vanes.
While the phenomenon typically can be avoided, at times of occurrence it may cause critical damage and lead to substantially reduced lifetimes for the components involved.
During his PhD-work, Kristian Sagmo has investigated the possibility of using rounded serrations, as well as a set of vortex generators, in order to effectively dampen the vibrations of vanes due to regular vortex shedding.

The results indicate that vortex generators can substantially reduce the vibrations occurring during resonance, while impairing minor pressure losses. Oppositely the serrations tested during experiments lead to increased vibrations during resonance. Discussions of the implications on design are made in the project documents.

Can lead to increased expected life-time for turbine-components.
The methods mentioned have been tested at the Waterpower laboratory of NTNU, and is currently on an early stage. The knowledge gained can be used for further development and subsequent implementation can be put to use either at the design stage for new turbines or for after-market solutions at existing power plants.

The method has commercial potential since it may lead to increased lifetime for turbines and pumps.
The results from the project have been made publicly available through open-access publications in the form of research articles and a doctoral thesis:

Trailing edge vortex shedding in hydraulic turbines and the effect of stream-wise vorticity on vortex-induced vibrations (doctoral thesis)
Vortex generator's effect on trailing edge vortex shedding and fluid structure interaction

RESEARCH IN HYDROCEN

FISH GUIDING INNOVATION SAVES FISH WHILE MAINTAINING POWER PRODUCTION

Expectations were sky high for the fish fence that was tested with tagged wild salmon smolts in the River Mandal in spring 2021. And the results came through: The new solution successfully guided 100% of the smolts, and no fish swam though the racks

Fish need to migrate to secure food and reproduction, and many solutions are developed to help fish swim upriver. However, the current technology for guiding fish back past the power intakes and downriver towards the sea or other feeding locations are more challenging and often very costly in large systems. The developed solution can save fish in regulated rivers worldwide, and the guiding system is ready to be produced and installed at a large scale.

The solution was developed through the collaboration of several fields of expertise: Biologists, engineers, hydrologists and experts from the hydropower industry. The idea and design was developed by researchers at NINA, NTNU,SINTEF and ETH Zurich, with support from the power producer Agder Energi. The local mechanical company STEIS constructed and built the guiding fence.

Even though some of the fish still found their way into the power station the concept was proven to work, and with some adjustments researchers believe they can save even more fish. They will now further develop the design to apply to more species than salmon, such as the endangered eel.

Contact:
Torbjørn Forseth, NINA
Svein Haugland, Agder Energi
Tjøl Eiken, Steis Mekaniske verksted

The guiding rack has 5 cm wide openings with plenty of space for salmon smolts to pass through, but they are positioned to create small eddies that together make a current that flows perpendicular to the water that flows towards the hydropower intake.

PhD-student Halvor Kjærås did hydraulic measurements that confirmed the parallel velocities along the rack.

COVID-19

1

The Covid pandemic has influenced us in every aspect of life the last two years. Despite several challenging situations HydroCen researchers have managed to deliver world-leading research results even when laboratories were closed, staff could not come to work – or even enter the country, and equipment did not arrive as planned. Our scientists have found ways to cooperate and move forward, work around the issues and even make them into something positive. In the hope that these problems are mainly behind us, we look back at some of the challenges we have faced.

2

"PhD fellow Hossein Ehya has really learned that Covind-19 presents challenges. On March 11th 2019, he was with his supervisor and a laboratory engineer from the Department of Electrical Power Engineering on an inspection of the Nea power plant. Here, instrumentation and testing on one of the generators were planned. Necessary data about the machine was also obtained. The following week, the tests were to be carried out. On March 12th though, the Prime Minister of Norway held the famous press conference that closed the country and the tests were not carried out until January 2021. They were very successful and showed that his ideas on fault detection worked in a power station in operation."

3

"Through the project HYCANOR (Partnership on Sustainable Hydropower in Canada and Norway,) we have had a collaboration between Norwegian and Canadian research communities. Because of Covid-19, we have unfortunately not been able to realise all the plans for visits and student exchanges and travel, but we have benefited a lot from other things, such as a special issue of the journal Hydrobiologica dedicated to the environmental effects of hydropower in Norway, Canada and Brazil."

4

"Students and a supervisor from the Waterpower Laboratory have been to Steindalen and Støylselva power plants located on in the municipality of Florø. Despite Covid, they were able to carry out turbine efficiency- and head loss measurements in collaboration with HydroCen partners ENESTOR and Captiva."

5

"One of the main challenges that was indirectly caused by Covid is delayed deliveries of various equipment. This was the case for projects that needed genetic analysis. Extraction kits and other necessary equipment were in high demand and deliveries were delayed, which again caused delayed analysis of genetic samples such as eDNA. Luckily, the staff at NINAs genetic laboratory is flexible and creative and managed to get access to equipment and solve the problems with relatively short delays."

6

"In November 2021 our PhD-candidate Ishwar Joshi finally arrived in Trondheim, after many months of COVID-delays and a 12-day (!) journey from Nepal to Norway. He will work on numerical modeling of sediment handling and is financed by HydroCen via Open Calls for one year and via Energize Nepal for two years. He has worked at Hydrolab in Nepal. Mesmerize is an Open Calls project in work package 1 and task 3, sediment handling. We were happy he arrived at last!"

7

"We have been able to perform the field work and other main functions to keep our projects going. We have had a digital researcher days to keep up with each others research, and we have become a lot better at digital meetings."

8

"The main challenge Covid has presented is the absence of physical meetings. Especially when it comes to interdisciplinary projects, digital meetings cannot replace social meetings. Luckily, it seems like we can start having meetings and workshops in person again. Covid has really made it clear to me that social interactions are vital for interdisciplinary work."

NEW PROJECTS IN HYDROCEN:

In HydroCen we have set aside extraordinary research funds that we have named "Open Calls". The purpose is to have funds for new projects with external funding during HydroCen's 8-year life that take into account changes and new needs in society and industry, facilitate the implementation of innovations from HydroCen, as well as ensuring the center's objectives, strengthening HydroCen's research in strategic topics, stimulates interdisciplinary research and international cooperation, and ensure good priorities and growth in the research portfolio.

In 2021, we launched 22 new projects of various size and scope:

Hydropower Structures

Mesmerise
The aim of this project is to improve the toolbox for predicting the behavior of sediments around a hydropower plant, both in the upstream and downstream river sections.
Project leader: Nils Rüther, NTNU.
Duration: 01.01.2021-31.12.2022

Rock support dimensioning, RockDim
The topic in this project is the challenges with swelling rocks with flexible operation of hydropower. The aim is to develop a project to further research the connection between swelling pressure and the need to secure hydropower tunnels with weak zones and swelling clay, as described in the PhD work of HydroCen candidate Lena Selen.
Project leader: Krishna Panthi, NTNU.
01.01.2021-31.12.2022

Turbine and generators

SediRes
This project is a continuation of the work Kathmandu University and NTNU has on sediment erosion in hydro turbines. The project will collaborate with WP-1.3, WP 2.1 and the Hydro Himalaya project.
The project started in December 2021 and a female PhD candidate at Kathmandu University has been recruited.
Project leader: Sailesh Chitrakar, NTNU
Duration: 01.12.2021-30.06.2024

HiFlex - HydroStator II
Espen Eberg (NTNU), project leader
01.11.2021-28.02.2022

Peltonturbin Prototyp efficiency measurements
Improve efficiency measurements in Pelton turbines. Optimise operation of the power plant and run with greater flexibility.
Project leader: Bjørn Winther Solemslie, NINA
Duration: 01.08.2021-30.09.2023

Measurement and modeling of dynamics and dynamic load in hydropower systems
The aim of this project is to find a way to measure the effect of the waterway on the powergrid/generator and the effect from the power grid/generator to the waterway.
Project leader: Tor Inge Reigstad, SINTEF
01.01.2021-30.06.2022

Market and services

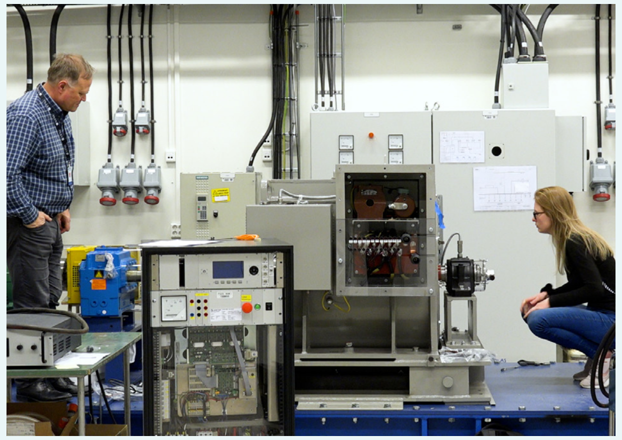
Pricing and modeling challenges in a renewable power system
This a pre-project used to get an overview of relevant literature and to develop ideas for a KSP project application with the subject how to model 100 renewable electricity system. The KSP application was sent to the Research Council February 9.
Project leader: Birger Mo, SINTEF
Duration: 08.01.2021-31.03.2022

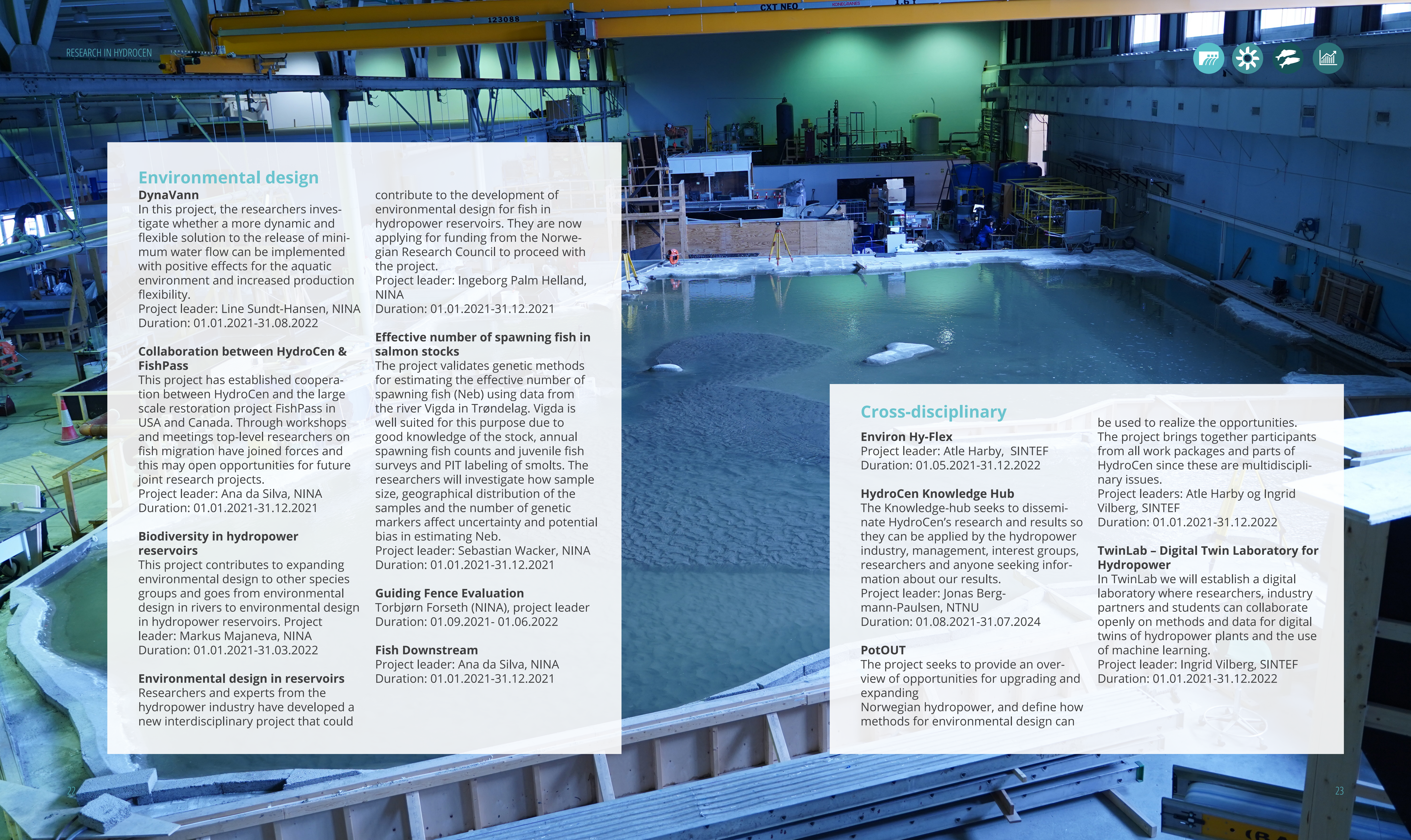
Measures for hydropower flexibility, FlexMet
The aim of this project is to develop and evaluate properties of simple measures for hydropower flexibility and to see how these measures are affected by different types of environmental constraints. The evaluation part is carried out with detailed calculations for a few real water courses.
Project leader Arild Helseth, SINTEF
Duration: 01.01.2021-31.12.2022

Electricity Market Models for the Future Power Grid: A US-European Review
There are intense debates about the ability of current electricity markets to provide cost-efficient system solutions, adequate incentives for individual market participants, and whether the ongoing grid transformation require new electricity market designs. This project has reviewed existing literature on electricity market models in the US and Europe, and focused on tools developed by the national labs in the United States and by NTNU and SINTEF Energy Research in Norway.
Project leader: Michael Belsnes, SINTEF.
Duration: 01.01.2021-31.12.2022

Penalties in ProdRisk
The purpose of the project is to increase understanding and to provide information on how penalties used to model restrictions in with Stochastic Dual Dynamic Programming (SDDP), such as the ProdRisk model, affect water values and thus the operation of the system. The work is directly linked to the SDDP methodology and new results will be implemented in the ProdRisk prototype.
Project leader: Birger Mo, SINTEF
Duration: 01.01.2021-31.12.2021

Toolchains
Cooperation with partners in Brazil and USA on a scientific article on the subject "Hydropower toolchains scheduling".
Project leader: Arild Helseth, SINTEF
Duration: 01.01.2021-31.12.2022





Environmental design

DynaVann
In this project, the researchers investigate whether a more dynamic and flexible solution to the release of minimum water flow can be implemented with positive effects for the aquatic environment and increased production flexibility.
Project leader: Line Sundt-Hansen, NINA
Duration: 01.01.2021-31.08.2022

Collaboration between HydroCen & FishPass
This project has established cooperation between HydroCen and the large scale restoration project FishPass in USA and Canada. Through workshops and meetings top-level researchers on fish migration have joined forces and this may open opportunities for future joint research projects.
Project leader: Ana da Silva, NINA
Duration: 01.01.2021-31.12.2021

Biodiversity in hydropower reservoirs
This project contributes to expanding environmental design to other species groups and goes from environmental design in rivers to environmental design in hydropower reservoirs. Project leader: Markus Majaneva, NINA
Duration: 01.01.2021-31.03.2022

Environmental design in reservoirs
Researchers and experts from the hydropower industry have developed a new interdisciplinary project that could contribute to the development of environmental design for fish in hydropower reservoirs. They are now applying for funding from the Norwegian Research Council to proceed with the project.
Project leader: Ingeborg Palm Helland, NINA
Duration: 01.01.2021-31.12.2021

Effective number of spawning fish in salmon stocks
The project validates genetic methods for estimating the effective number of spawning fish (Neb) using data from the river Vigda in Trøndelag. Vigda is well suited for this purpose due to good knowledge of the stock, annual spawning fish counts and juvenile fish surveys and PIT labeling of smolts. The researchers will investigate how sample size, geographical distribution of the samples and the number of genetic markers affect uncertainty and potential bias in estimating Neb.
Project leader: Sebastian Wacker, NINA
Duration: 01.01.2021-31.12.2021

Guiding Fence Evaluation
Torbjørn Forseth (NINA), project leader
Duration: 01.09.2021- 01.06.2022

Fish Downstream
Project leader: Ana da Silva, NINA
Duration: 01.01.2021-31.12.2021

Cross-disciplinary

Environ Hy-Flex
Project leader: Atle Harby, SINTEF
Duration: 01.05.2021-31.12.2022

HydroCen Knowledge Hub
The Knowledge-hub seeks to disseminate HydroCen's research and results so they can be applied by the hydropower industry, management, interest groups, researchers and anyone seeking information about our results.
Project leader: Jonas Bergmann-Paulsen, NTNU
Duration: 01.08.2021-31.07.2024

PotOUT
The project seeks to provide an overview of opportunities for upgrading and expanding
Norwegian hydropower, and define how methods for environmental design can be used to realize the opportunities. The project brings together participants from all work packages and parts of HydroCen since these are multidisciplinary issues.
Project leaders: Atle Harby og Ingrid Vilberg, SINTEF
Duration: 01.01.2021-31.12.2022

TwinLab – Digital Twin Laboratory for Hydropower
In TwinLab we will establish a digital laboratory where researchers, industry partners and students can collaborate openly on methods and data for digital twins of hydropower plants and the use of machine learning.
Project leader: Ingrid Vilberg, SINTEF
Duration: 01.01.2021-31.12.2022

INTERNATIONAL INTEREST IN HYDROCEN

Despite the world wide pandemic putting a stop to most travelling, HydroCen researchers have continued the collaboration with our international partners in 2021. Through video meetings, calls, webinars and workshops we have published articles together, started new projects and made new colleagues.
The international collaboration in HydroCen is organized along five main axes, ensuring knowledge transfer to/from relevant regions, excellent research groups and participation in technological fora.

The two strongest axes are geographically focused towards the Nordic and European regions, the third axis is towards Asia where large-scale development of hydropower is ongoing. The forth axis to America and the fifth axis is towards the participation in technological fora. More than 60 international institutions are in contact with HydroCen through these axes.

SWEEDEN, ÄLVKARLEBY:
Vattenfall is partner in HydroCen, contributing with world class laboratories to study fish migration, dam safety, turbines, generator operation and digitalisation tools.

CANADA:
In the HYCANOR network we have collaborated on a special hydropower edition of the journal Hydrobiologica.

USA:
Strategic cooperation with UsDOE and several national Research Laboratories continues. We have also established a connection to Fish-Pass, a renowned project on fish migration with some of the leading experts in the field.

BRAZIL:
Cooperation with cePeL (electrical energy Research Center) for possible cooperation on developing models for hydropower planning.

Writing a scientific article together with authors from Rio de Janeiro State University (Brazil) and Argonne National Laboratories (USA) on the topic "Hydropower scheduling toolchains".

SWITZERLAND:
Researcher cooperation, and Scientific committiee-member Prof dr.Thomas staubli.

EU:
HydroCen is well represented in management and operation of EERA's Joint Program on Hydropower. The main activities in 2021 have been the establishment of consortiums for the Horizon Europe calls on projects which are relevant for the partners.

HydroFlex is in its final stage, and many publications and reports can be found on its website.

ALBANIA, MOGLICË:
Lena Selen presented her Phd Thesis investigating effects of swelling rock mass on stability and support in hydropower tunnels.

NEPAL, KATHMANDU:
Further strengthening of the research cooperation between Nepal, India and Norway. The Energize-Nepal-project is still going strong with yearly student exchange and attendance at the yearly conference chRT at Kathmandu University. Several of our PhD also come from Kathmandu University and HydroLab. In 2021 the associated NORAD funded project HydroHimalaya was launched. Through this project 10 PhDs and 20 Masters within Hydrpower will be educated.

INDIA, IIT ROORKEE:
The Indian institute of Technology Roorkee continue to work together with HydroCen researchers and Kathmandu university to develop sediment resistant Francis turbines and new methods for data collection and modelling.

AUSTRALIA:
Cooperation with Hydro Tasmania, and the state government of Tasmania.

Ivar Arne Børset, Chairman of the Board

BRIEF FROM THE BOARD

We are proud to see that HydroCen received very good feedback from the Norwegian Research Council, and was approved funding for another three years of operation.

HydroCen represents a driving force for hydropower development through extensive fieldwork, collaborative workshops and initiation of new projects and activities. Times are shifting ever more quickly, and this definitely applies to the future role of hydropower. With rising energy prices in winter 2021-2022, the Norwegian government is giving clear signals indicating a need for further development of our power system, involving a need for upgrading and possible expansion of hydropower. Thus, in 2021 we have initiated new projects and discussed future plans to be able to meet the upcoming needs in a rapidly evolving energy and climate discourse.

HydroCen is well managed, and scientific excellence is in focus, coupled with a strong ability to deliver and a high level of industry involvement. The Board appreciates the close cooperation and fruitful discussions with the management team, work package leaders, and members of HydroCen.

The centre is also producing impressing ripple effects in terms of a growing portfolio of associated projects, both nationally and internationally. The list of associated projects is now equally large in terms of budget and activity as HydroCens internal portfolio of projects, and includes activities in Europe, USA and Asia.

Looking forward, we expect that communication and implementation of research results will get an even higher priority. We have great belief in Kunnskapsbanken, and trust that all members of HydroCen will contribute to and benefit from more communication to be able to harvest the potential that lies in research results. To solve coming challenges in a more flexible power system, we need to pull together and find those solutions.

The HydroCen board gathered for a strategy meeting in Flåm in 2021. Eivind Heløe (Energi Norge), Ingeborge Palm Helland (NINA), Sveinung Løset (deputy representative) (NTNU), Liv Randi Hultgreen (Senterleder), Erik Skorve (Eviny), Celine Setsaas (Hafslund Eco), Knut Samdal (SINTEF), Inga Katrine Nordberg (NVE). Chairman of the board Ivar Arne Børset (Statkraft) participated digitally and is therefore not represented on the picture

Ivar Arne Børset
Statkraft

Eivind Heløe
Energi Norge

Olav Bolland
NTNU

Ingeborg Palm Helland
NINA

Knut Samdal
SINTEF

Erik Skorve
Eviny

Inga Katrine Nordberg
NVE

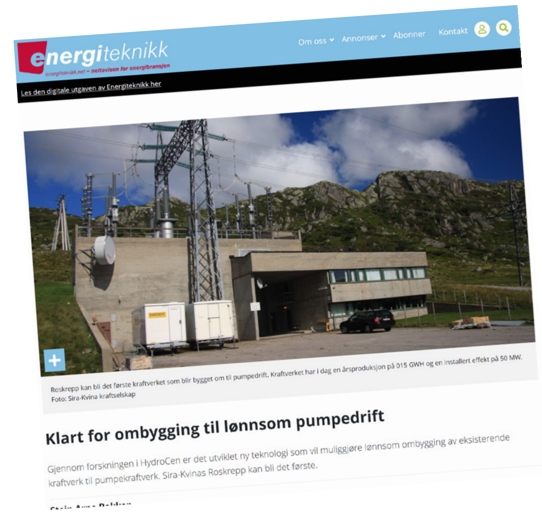
Celine Setsaas
Hafslund Eco

Harald Rikheim
The Research Council of Norway

Liv Randi Hultgreen
NTNU/Board Secretary

HYDROCEN IN THE MEDIA

In 2021 HydroCen researchers have participated in a large range of media outlets such as national tv, radio and newspapers, as well as local media and technical magazines. They have also featured in podcasts and social media content to promote the research done in HydroCen – both in our own channels and in collaboration with others. In total, HydroCen and our researchers have been mentioned in more than 100 articles and broadcasts. Researchers also participated in more than 40 popular science webinar presentations.



OUR OULETS

Blog:
12 blog posts with information, news and research results from HydroCen in 2021, and an increasing number of followers.

Vannposten:
Weekly newsletter for researchers and partners. 21 publications and about 200 recipients

Website:
Information and contact details for all projects and researchers in HydroCen. Publications and innovations are also listed on www.hydrocen.no.

Webinar:
More than 40 webinars posted on Hydro- Cens YouTube-channel and others.

SOCIAL MEDIA

542

Twitter:
Sharing news and articles, and follow- ing the public debate. 542 followers and increasing.

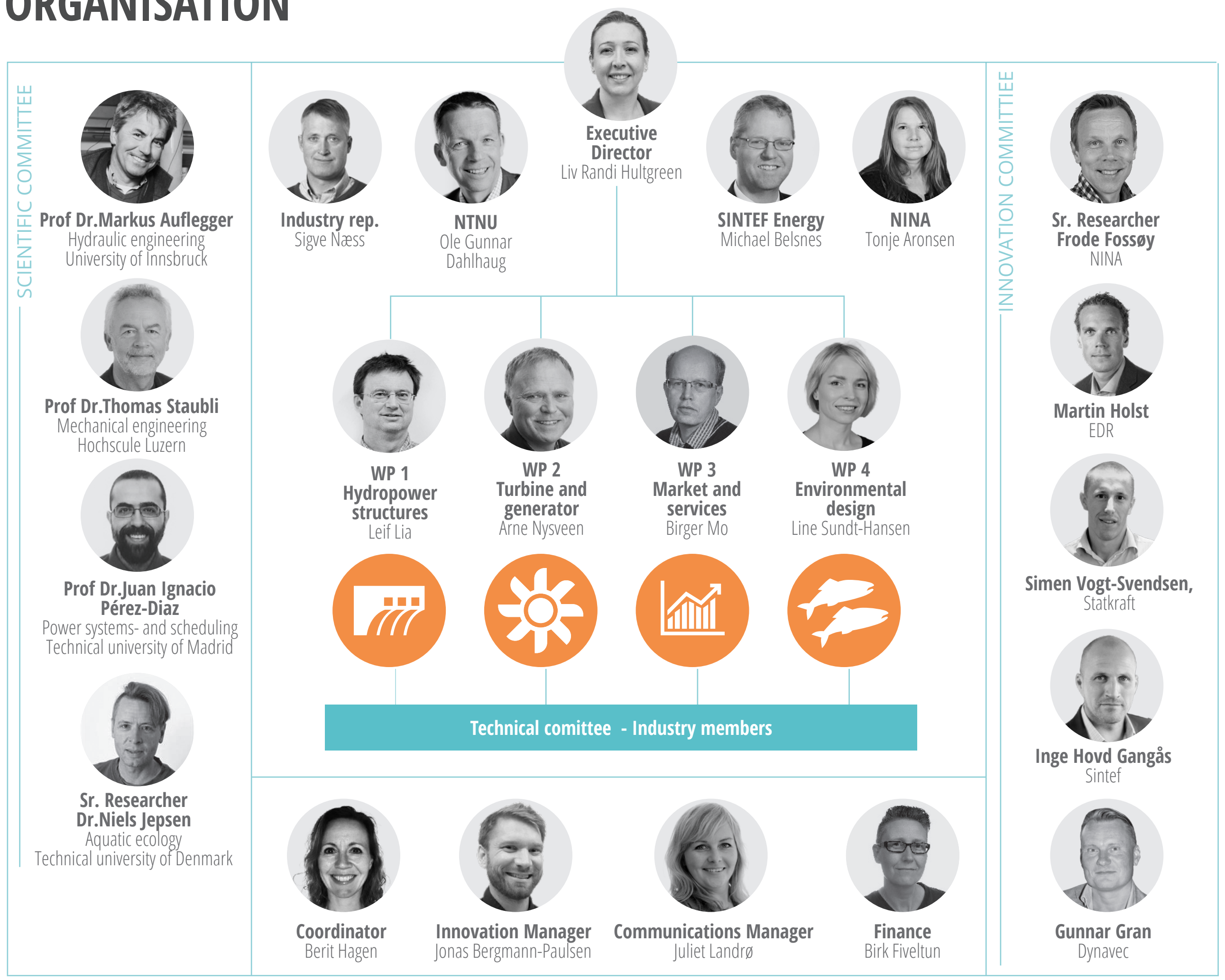
518

Facebook:
Sharing articles and news with our 518 followers. Our top post reached more than 6000 viewers.

404

LinkedIn:
404 followers and aiming to increase activity

ORGANISATION



Board

Name	Institution	Function
Ivar Arne Børset	Statkraft	Chairman of the Board
Ingeborg Palm Helland	NINA	Board member
Knut Samdal	SINTEF	Board member
Eivind Heløe	Energi Norge	Board member
Inga Katrine Nordberg	NVE	Board member
Erik Skorve	Eviny	Board member
Celine Setsaas	E-CO	Board member
Olav Bolland	NTNU	Board member
Liv Randi Hultgreen	NTNU	Executive Director/Board Secretary
Harald Rikheim	NRC	Observer
Juliet Landrø	NINA	Observer
Berit Garberg Hagen	NTNU	Coordinator
Lars Grøttå	NVE	Deputy board member
Ole-Morten Midtgård	NTNU	Deputy board member
Petter Støa	Sintef Energi	Deputy board member
Norunn Myklebust	NINA	Deputy board member
Terese Løvås	NTNU	Deputy board member
Jane Berit Solvi	Skagerak	1. deputy board member
Tormod Eggan	TrønderEnergi	2. deputy board member
Bjørn Honningsvåg	Lyse	3. deputy board member

Executive Management Team and Admnistration

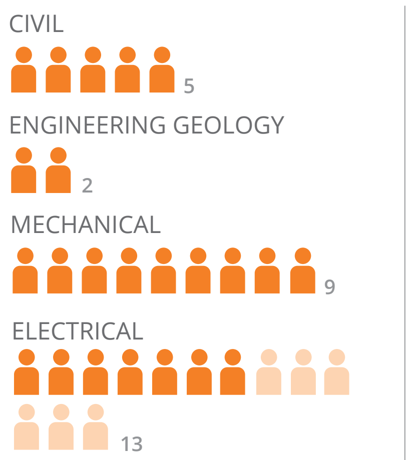
Name	Institution	Function
Liv Randi Hultgreen	NTNU	Executive Director/Board Secretary
Ole Gunnar Dahlhaug	NTNU	Member
Tonje Aronsen	NINA	Member
Michael Belsnes	SINTEF	Member
Sigve Næss	Eviny	Member
Berit Garberg Hagen	NTNU	Coordinator
Juliet Landrø	NTNU	Communications officer
Birk Fiveltun	NTNU	Finance officer
Jonas Bergmann-Paulsen	NTNU	Innovation Manager

Researchers

Name	Institution	Main research area
Arne Nysveen	NTNU	Turbine and generators
Bjørnar Svingen	NTNU	Turbine and generators
Chirag Trivedi	NTNU	Turbine and generators
Elena Pummer	NTNU	Hydropower structures
Fjóla G. Sigtryggsdóttir	NTNU	Hydropower structures
Håkon Sundt	NTNU	Hydropower structures
Johannes Kverno	NTNU	Hydropower structures
Jonas Kristiansen Nøland	NTNU	Turbine and generators
Kjetil Uhlen	NTNU	Turbine and generators
Knut Alfredsen	NTNU	Environmental design
Krishna Panthi	NTNU	Hydropower structures
Leif Lia	NTNU	Hydropower structures
Magnus Korpås	NTNU	Market and services
Nils Reidar Bøe Olsen	NTNU	Hydropower structures
Nils Ruther	NTNU	Hydropower structures
Ole Gunnar Dahlhaug	NTNU	Turbine and generators
Pål-Tore Storli	NTNU	Turbine and generators
Roy Nilsen	NTNU	Turbine and generators
Siri Stokseth	NTNU	Hydropower structures
Stein-Erik Fleten	NTNU	Market and services
Subhjit Kadia	NTNU	Hydropower structures
Theo Dezert	NTNU	Hydropower structures
Tor Haakon Bakken	NTNU	Market and services
Torbjørn Nielsen	NTNU	Turbine and generators
Ana Teixeira da Silva	NINA	Environmental design
Anders Foldvik	NINA	Hydropower structures
Audun Ruud	NINA	Environmental design
Berit Köhler	NINA	Environmental design
Bjørn Winther Solemslie	NINA	Environmental design
David Barton	NINA	Environmental design
Eli Kvingedal	NINA	Environmental design
Finn Økland	NINA	Environmental design
Frode Fossøy	NINA	Environmental design
Håkon Sundt	NINA	Environmental design
Ingeborg Palm Helland	NINA	Environmental design
Ingebrigt Uglem	NINA	Environmental design
Karl Øystein Gjelland	NINA	Environmental design
Line Sundt-Hansen	NINA	Environmental design
Margrete Skår	NINA	Environmental design
Markus Majaneva	NINA	Environmental design
Richard Hedger	NINA	Environmental design
Rolf Sivertsgård	NINA	Environmental design
Tonje Aronsen	NINA	Environmental design
Torbjørn Forseth	NINA	Environmental design
Øystein Aas	NINA	Environmental design
Ana Adeva Bustos	SINTEF	Environmental design
Arild Helseth	SINTEF	Market and services
Arnt Ove Eggen	SINTEF	Market and services
Atle Harby	SINTEF	Environmental design
Atsede G. Endegnanew	SINTEF	Turbine and generators
Bendik Torp Hansen	SINTEF	Hydropower structures
Birger Mo	SINTEF	Market and services
Christian Øyn Naversen	SINTEF	Market and services
Eivind Solvang	SINTEF	Turbine and generators
Ellen Krohn Aasgård	SINTEF	Market and services
Espen Eberg	SINTEF	Turbine and generators
Hans Ivar Skjelbred	SINTEF	Market and services
Hans Olaf Hågenvik	SINTEF	Market and services
Henrik Enoksen	SINTEF	Turbine and generators
Ingrid Vilberg	SINTEF	Market and services
Julie Charmasson	SINTEF	Hydropower structures
Jørn Foros	SINTEF	Turbine and generators
Karl Merz	SINTEF	Turbine and generators
Kjell Ljøkelsøy	SINTEF	Turbine and generators
Lennart Schönfelder	SINTEF	Market and services
Linn Emelie Schäffer	SINTEF	Market and services
Marcell Szabo-Meszaros	SINTEF	Environmental design
Maren Istad	SINTEF	Turbine and generators
Mauro Corelli	SINTEF	Market and services
Michael Belsnes	SINTEF	Market and services
Olve Mo	SINTEF	Turbine and generators
Sambeet Mishra	SINTEF	Market and services
Siri Mathisen	SINTEF	Market and services
Stefan Rex	SINTEF	Market and services
Sverre Hvidsten	SINTEF	Turbine and generators
Tuan T. Nguyen	SINTEF	Turbine and generators
Sailesh Chitrakar	KU	Turbine and generators
Roger Olsson	NGI	Turbine and generators
Ulrich Pulg	NORCE	Environmental design
Jochen Aberle	TU Braunschweig	Associated project
Bernt Lie	USN	Turbine and generators
Gunne Hegglid	USN	Turbine and generators

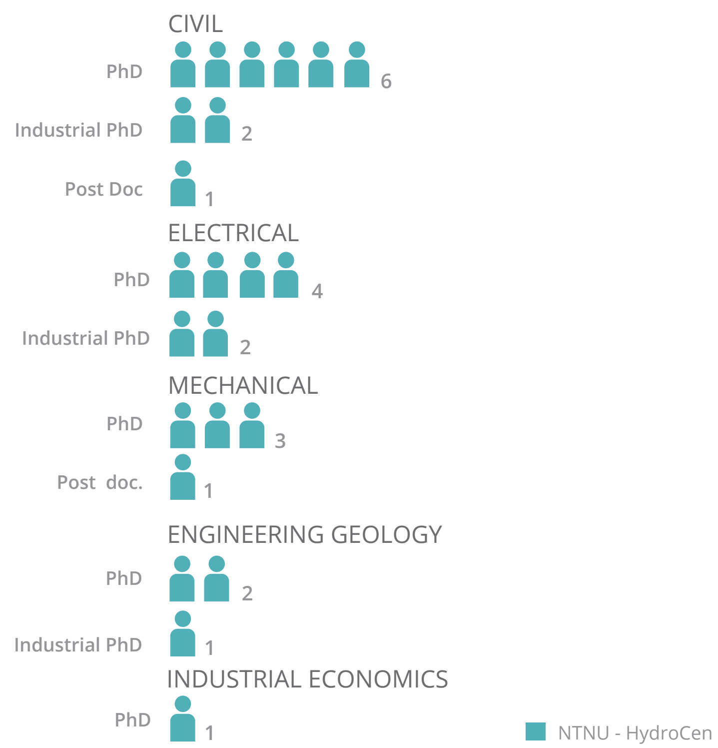
MASTER STUDENTS

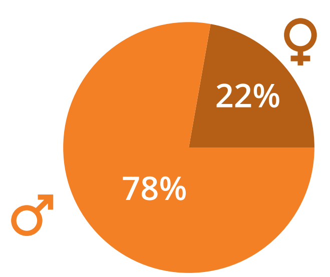
In 2021 we had a total of 29 master students at NTNU and The University of South-Eastern Norway (USN) within the field of hydropower. The distribution between the disciplines civil, engineering geology, mechanical and electrical is shown in the figure below.



PHD AND POST DOCS.

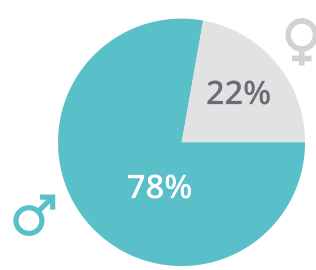
In 2021 a total of 23 PhD and Post docs were in HydroCen. They worked within Civil, Engineering Geologyy, Mechanical, Electrial and Industrial economics.





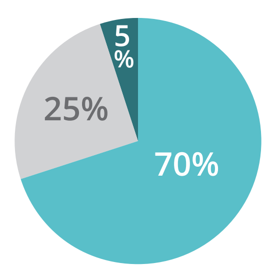
Gender distribution

Women
Men



Gender distribution

Women
Men



Distribution between PhD, Post doc. and industrial PhD and post doc

Industrial PhD
PhD
Post doc.

PhD and Post doc. in HydroCen, active in 2021

Name	PhD Post doc.	Gender	Nationality	Topic	Period	Department
Andreas Kleiven	PhD	M	Norwegian	Investment Decisions in Upgrading and Refurbishment of Hydropower Plants	2017-2020	Industriel economics
Bibek Neupane	PhD	M	Nepalese	Long-term impact on unlined tunnels of hydropower projects due to frequent start stop sequences	2017-2021	Engineering Geology
Diwash Lal Maskey	PhD	M	Nepalese	Sediment handling at the intake of the hydropower plants: A toolbox for decision making	2018-2021	Civil
Geir Helge Kiplesund	PhD	M	Norwegian	Embankment dam safety under extreme loading conditions: Breaching of embankment dams	2019-2022	Civil
Halvor Kjærås	PhD	M	Norwegian	Modeling of fish guidance by floating devices	2018-2022	Civil
Helene Dagsvik	PhD	F	Norwegian	Reversible Pump-Turbines in Existing Power Plants	2017-2022	Mechanical
Henki Ødegaard	PhD	M	Norwegian	Optimization of test methods and design of transition zones in unlined pressure tunnels	2017-2021	Engineering Geology
Hossein Ehya	PhD	M	Iranian	Electromagnetic Analysis and Online Fault detection of Hydropower Generators	2018-2021	Electrical
Håkon Sundt	PhD	M	Norwegian	Environmental design for multiple interests under future flexible hydropower operation	2017-2021	Civil
Igor Iliev	Post doc.	M	Macedo-nian	Focused research in hydraulic turbines	2020-2022	Mechanical
Ishwar Joshi	PhD	M	Indian	Numerical Simulation of Sediment Transport in Rivers and Reservoirs	2021-2024	Civil
Kristian Sagmo	Post doc.	M	Norwegian	Design and testing of axial turbine blade-stage for damping measurements connected to complex mode shapes	2021-2023	Mechanical
Lena Selen	PhD	F	Norwegian	Effects of swelling rock and swelling clay in water tunnels	2017-2021	Engineering Geology
Linn Emelie Schäffer	PhD	F	Norwegian	Modelling of Environmental Constraints for Hydropower Optimization Problems	2020-2023	Electrical
Livia Pitorac	PhD	F	Romanian	Upgrading of hydropower plants to pumped storage plants: reconstruction and improvements of the tunnel system	2017-2021	Civil
Michiel Desmedt	PhD	M	Dutch	FEA analysis of a novel single stator-dual rotor machine topology	2021-2024	Electrical
Nirmal Acharya	PhD	M	Nepalese	Design of a Francis turbine that accomodates high sediment concentration	2018-2021	Mechanical
Ola Haugen Havrevoll	PhD	M	Norwegian	Rock traps in pumped storage and peaking power plants	2017-2022	Civil
Raghbendra Tiwari	PhD	M	Nepalese	Frequency converter solutions and control methods for variable speed operation of pump storage plant	2018-2022	Electrical
Shohreh Monshizadeh	PhD	F	Iranian	The Flexible Hydro Power Unit	2018-2021	USN
Subhojit Kadia	PhD	M	Indian	Numerical modelling of sediment bypass tunnels	2020-2023	Civil
Theo Dezert	Post doc.	M	French	Plastring av damtå og bruddforløp i fyllingsdammer	2021-2023	Civil
Tor Inge Reigstad	PhD	M	Norwegian	Grid Integration of Variable Speed Hydro Power Plant	2018-2021	Electrical

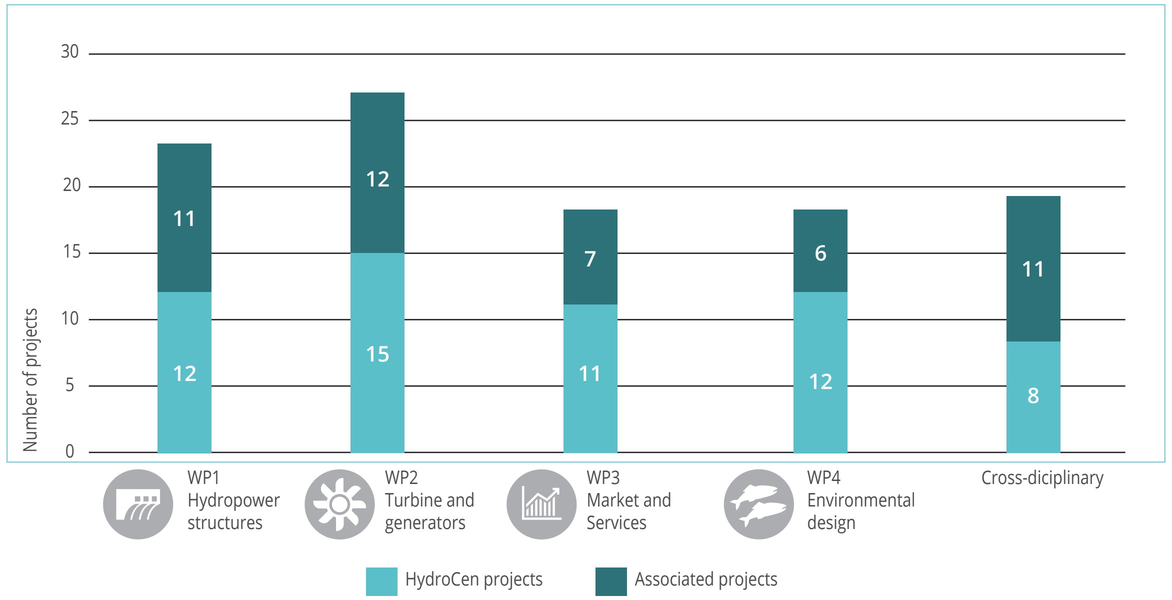
FINANCIAL STATEMENT HYDROCEN 2021

All figures in 1000 NOK

Funding 2021	Funding	In-kind	Total
The Research Council of Norway	31 056		31 056
Industry partners	9 371	4 312	13 683
Research partners		16 096	16 096
Total funding 2020	**40 427**	**20 408**	**60 835**
Revenue 2021	**Funding**	**In-kind**	**Total**
Sintef Energi	16 699	5 823	22 522
NINA	7 145	2 666	9 811
NGI		921	921
USN	308	529	837
KU	314	225	539
NTNU	15 961	5 932	21 893
Industry in-kind		4 312	4 312
Total Costs 2020	**40 427**	**20 408**	**60 835**

PROJECTS OVERVIEW 2021

A total of 105 projects related to hydropower were ongoing in 2021. 47 of these are associated projects within hydropower where HydroCen's researchers are involved.



HydroCen Projects

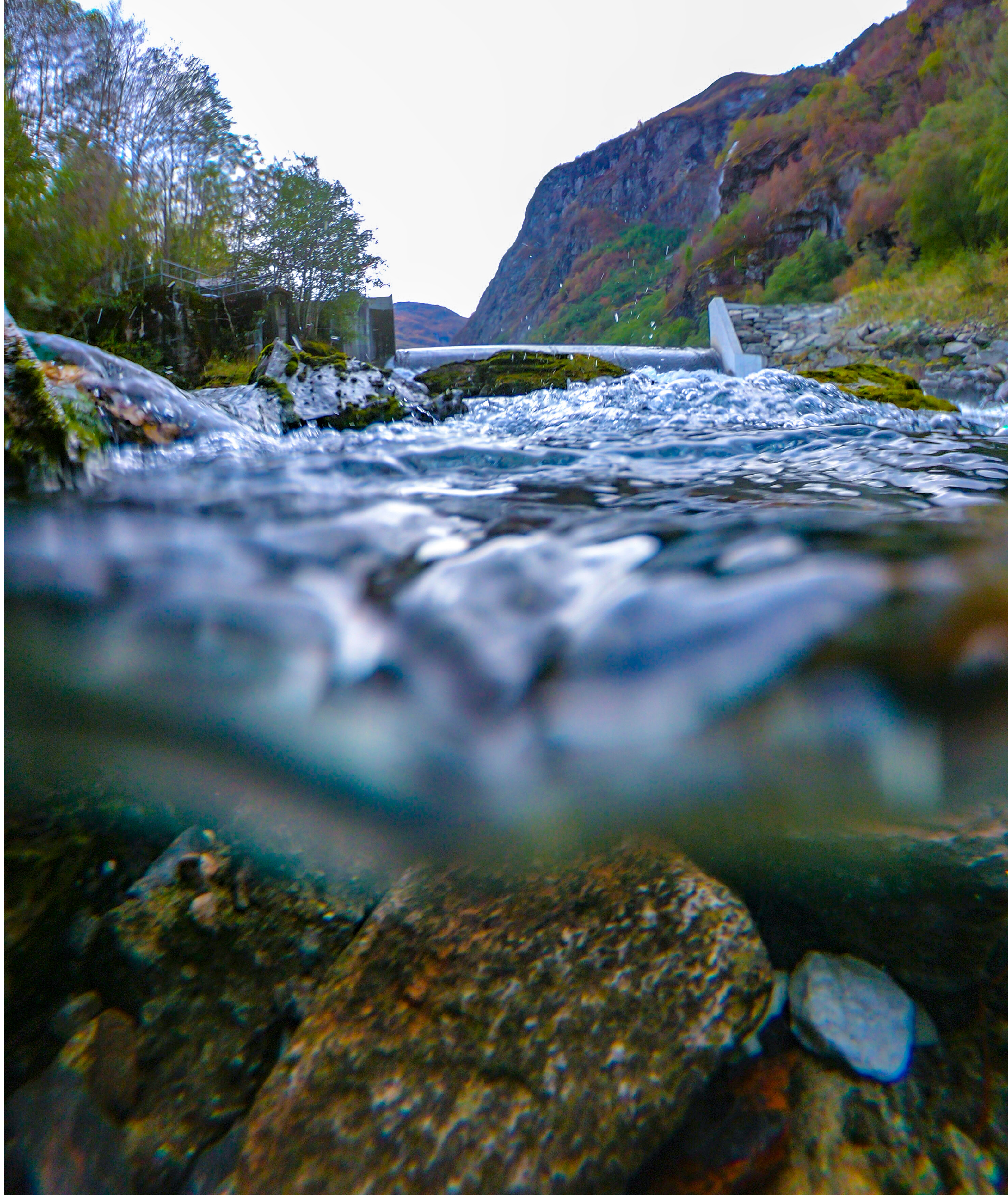
Project name	Project leader	Field of study
1.1 Tunnels, penstocks and surge chambers	Krishna Panthi	Hydropower structures
1.2 Dam construction and dam saftey	Fjola G. Sigtryggsdottir	Hydropower structures
1.3 Sediment handling	Nils Rüther	Hydropower structures
1.4 Fish friendly hydropower intakes	Leif Lia	Hydropower structures
2.1 Variable speed operation	Olve Mo	Turbine and generators
2.2 Fatigue loads on turbines	Torbjørn Nielsen	Turbine and generators
2.3 Pump turbines in existing power plants	Pål-Tore Storli	Turbine and generators
2.4 Turbine and Generator Lifetime	Maren Istad	Turbine and generators
2.5 Flexible Hydropower Unit	Kjetil Uhlen	Turbine and generators
2.6 New Design of Guide Vanes	Pål-Tore Storli	Turbine and generators
3.1 Future markets and prices	Birger Mo	Market and services
3.2 Remaining useful life, failure probability	Arnt Ove Eggen	Market and services
3.3 Optimal hydro design in the future power system	Birger Mo	Market and services
3.4 Environmental constraints and uncertainties – impact on revenues	Arild Helseth	Market and services
3.5 Water resources assessment tool	Lennart Schönfelder	Market and services
4.1 Implementing and founding environmental design solutions (EDS)	Berit Köhler	Environmental design
4.2 Two-way Fish Migration	Ana da Silva	Environmental design
4.3 Environmental design	Atle Harby	Environmental design

New HydroCen projects (Open Calls)

Project name	Project leader	Field of study
5.1.2 Breaching of rockfill dams with core	Fjola G. Sigtryggsdottir	Hydropower structures
5.1.3 Mesmerise	Nils Rüther	Hydropower structures
5.1.4 Rock support dimensioningg	Krishna Panthi	Hydropower structures
5.1.5 Erosjonsikring oppstrøms på fyllingsdammer	Fjola G. Sigtryggsdottir	Hydropower structures
5.1.6 Utvidelse av flomløp	Leif Lia	Hydropower structures
5.1.7 Injisering av fyllingsdam	Leif Lia	Hydropower structures
5.1.8. Forprosjekt: Effektiv funksjonsforbedring av eksisterende bekkeinntak	Leif Lia	Hydropower structures
5.1.9. InSpillyFish - Øking av flomløpskapasitet med betre vandringsløysingar for fisk	Leif Lia	Hydropower structures
5.2.2 Francis Turbiner	Ole Gunnar Dahlhaug	Turbine and generators
5.2.3 Trykkpulsasjoner	Pål-Tore Storli	Turbine and generators
5.2.4 ElMag	Arne Nysveen	Turbine and generators
5.2.5 Asset Life	Eivind Solvang	Turbine and generators
5.2.6 Peltonturbin Prototyp virkningsgradsmålinger	Bjørn Winther Solemslie	Turbine and generators
5.2.7 Måling, beregning og modellering av dynamikk og dynamisk belastning i vann-kraftsystemer.	Tor Inge Reigstad	Turbine and generators
5.2.8 Identifisering av sprekkdannelser i løpehjul	Ole Gunnar Dahlhaug	Turbine and generators
5.2.9 SediRes	Sailesh Chitrakar	Turbine and generators
5.2.10 HiFlex - HydroStator II	Espen Eberg	Turbine and generators
5.3.1 Fagutvalgsmidler WP3	Birger Mo	Market and services
5.3.2 Priser og modelleringsutfordringer i et 100% fornybart kraftsystem	Birger Mo	Market and services
5.3.3 Environmental measures impact on hydro power system (FlexMet)	Arild Helseth	Market and services
5.3.4 Electricity Market Models for the Future Power Grid: A US-European Review	Michael Belsnes	Market and services
5.3.5 Penalties in ProdRisk	Birger Mo	Market and services
5.3.6 Toolchains	Arild Helseth	Market and services
5.4.1 Fagutvalgsmidler WP4	Torbjørn Forseth	Environmental Design
5.4.2 Fish Downstream	Ana da Silva	Environmental Design
5.4.3 Dynamisk minstevannføring i et miljødesign perspektiv	Line Sundt-Hansen	Environmental Design
5.4.4 Collaboration between HydroCen & FishPass	Ana da Silva	Environmental Design
5.4.5 Artsmangfold i magasiner	Markus Majaneva	Environmental Design
5.4.6 Miljødesign i magasin – søknadsutvikling	Ingeborg Palm Helland	Environmental Design
5.4.7 Effektivt antall gytefisk i laksebestander	Sebastian Wacker	Environmental Design
5.4.8 Dynavann-Fumidler	Line Sundt-Hansen	Environmental Design
5.4.9 Guiding Fence Evaluation	Torbjørn Forseth	Environmental Design
5.5.1 AlternaFuture	Kaspar Vereide	Cross-disciplinary
5.5.2 Valueflex	Michael Belsnes	Cross-disciplinary
5.5.3 Digitalization	Hans Ivar Skjelbred	Cross-disciplinary
5.5.4 Gold standard	Oddgeir Andersen	Cross-disciplinary
5.5.5 PotOUT: Potensiale for opprusting og utvidelse av vannkraft med miljødesign	Atle Harby og Ingrid Vilberg	Cross-disciplinary
5.5.6 TwinLab – Digital Twin Laboratory for Hydropower	Ingrid Vilberg	Cross-disciplinary
5.5.8 Kunnskapsbanken	Jonas Bergmann-Paulsen	Cross-disciplinary
5.5.9 Environ Hy-Flex	Atle Harby	Cross-disciplinary
5.6.3 EU (EERA) aktivitet	Ole Gunnar Dahlhaug	WP5 Open Calls
5.6.5 HydroPower Summit	Ole Gunnar Dahlhaug	WP5 Open Calls
5.6.8 Tverrfaglige grupper	Liv Randi Hultgreen	WP5 Open Calls
5.6.9 IAHR Asia 2021 internasjonalt arbeid	Ole Gunnar Dahlhaug	WP5 Open Calls

Associated Projects

Project name	Project leader	Field of study	Type	Project owner
ALPHEUS	Pål-Tore Selbo Storli	Cross-disciplinary	EU H2020	TU Delft
Capacity Building in Higher Education within Rock and Tunnel Engineering	Krishna K. Panthi	Cross-disciplinary	NORHED II	NTNU
CoBas	Christian Andresen	Market and services	IPN	SINTEF
DeGas	Ole Gunnar Dahlhaug	Cross-disciplinary	KPN	NTNU
DIRT-X	Nils Rüther	Market and services	EU H2020	NTNU
Elvemuslingens miljøkrav	Bjørn M. Larsen	Hydropower structures	Government	NINA
EnergizeNepal	Nawaraj Sanjel	Cross-disciplinary	Government	Kathmandu University
FishPath	Torbjørn Forseth	Environmental design	NFR	NINA
FIThydro	Peter Rutschmann	Turbine and generators	EU H2020	TU Münich
Fleksibel Sandfang (FlexS)	Kaspar Vereide	Turbine and generators	Industry	Sira Kvina Kraftselskap
FlomQ	Nils Rüther	Hydropower structures	IPN	Energi Norge
Francis-99	Chirag Trivedi	Environmental design	NTNU internal	NTNU
FranSed	Ole Gunnar Dahlhaug	Turbine and generators	Government	NTNU
HiFrancis	Ole Gunnar Dahlhaug	Turbine and generators	KPN	NTNU
HiFrancis FSI Toolkit	Martin Holst	Hydropower structures	IPN	EDRMedeso
HYCANOR	Ingeborg Palm Helland	Turbine and generators	INTPART	NINA
Hydraulic Research and Education Laboratory and Dam Safety in Ethiopia	Leif Lia	Cross-disciplinary	NORHED II	NTNU
HydroBalance	Michael Belsnes	Market and services	KPN	SINTEF
HydroCen Labs	Ole Gunnar Dahlhaug	Cross-disciplinary	RCN Infrastructure	NTNU
HydroConnect	Atle Harby	Market and services	KPN	SINTEF
HydroFLEX	Ole Gunnar Dahlhaug	Cross-disciplinary	EU H2020	NTNU
HydroStator	Arne Nysveen	Turbine and generators	KPN	NTNU
HyMo	Atle Harby	Environmental design	Government	SINTEF
HYPOS - Hydropower Suite	Nils Rüther	Turbine and generators	EU H2020	NTNU
IntHydro	Hossein Farahmand	Cross-disciplinary	IKT PLUSS	NTNU
JP hydropower/ EERA	Sara Heidenreich	Cross-disciplinary	RCN MVO	NTNU
Life expectancy calculations for Francis	Petter Østby	Turbine and generators	IPN	Rainpower
LitRo	Morten Kjeldsen	Hydropower structures	IPN	Flow Design Bureau
Miljødesign Mandalselva	Torbjørn Forseth	Environmental design	Industry	NINA
Miljødesignhåndbok for ørret i magasin	Ingeborg Palm Helland	Turbine and generators	Government	NINA
MonitorX	Maren Istad	Hydropower structures	IPN	Energi Norge
MultiSHARM	Marte Fodstad	Market and services	KPN	SINTEF
Nye miljørestriksjoner	Einar Kobro/ Ingeborg Graaba	Market and services	IPN	SINTEF
PlaF	Leif Lia	Hydropower structures	Industry	NTNU
PRIBAS	Arild Helseth	Hydropower structures	KPN	SINTEF
Reversible pumpeturbiner	Torbjørn Nielsen	Turbine and generators	Industry	NTNU
ROCARC	Charlie Chunlin Li	Hydropower structures	Samarbeidsprosjekt for samfunn & næring	NTNU
SafePASS	Torbjørn Forseth	Environmental design	KPN	NINA
SediPASS	Nils Rüther	Turbine and generators	KPN	NTNU, NVKS
Skred i magasin	Leif Lia	Hydropower structures	Government	NTNU
Stable Dams	Bård Arntsen	Hydropower structures	KPN	Norut
Strengthening the higher education at Kathmandu University	Ole Gunnar Dahlhaug	Cross-disciplinary	NORHED II	NTNU
STRIVAN	Siri Stokseth	Hydropower structures	IPN	NTNU
SusWater	Atle Harby	Environmental design	KPN	SINTEF
SysOpt	Thomas Øyvang	Market and services	KPN	USN
TunnelRoughness	Jochen Aberle	Cross-disciplinary	KPN	NTNU, NVKS



PUBLICATIONS

HydroCen has published 27 scientific publications in 2021. In addition our researchers have published multiple HydroCen Reports and participated on more than 25 conference papers and scientific presentations. Five candidates have completed their PhD thesis.

Level 2 papers (highest level)

Ehya, Hossein; Nysveen, Arne.
Comprehensive Broken Damper Bar Fault Detection of Synchronous Generators. IEEE transactions on industrial electronics (1982. Print) 2021. NTNU

Ehya, Hossein; Nysveen, Arne; Alfonso Antonino Daviu, Jose.
Advanced Fault Detection of Synchronous Generators using Stray Magnetic Field. IEEE transactions on industrial electronics (1982. Print) 2021. NTNU

Hiriyanna Rao Ravindra, Ganesh; Sigtryggsdottir, Fjola Gudrun; Lia, Leif.
Buckling analogy for 2D deformation of placed ripraps exposed to overtopping. Journal of Hydraulic Research 2021 ;Volum 59.(1) s. 109-119. NTNU

Neupane, Bibek; Panthi, Krishna Kanta.
Evaluation on the Efect of Pressure Transients on Rock Joints in Unlined Hydropower Tunnels Using Numerical Simulation. Rock Mechanics and Rock Engineering 2021 ;Volum 54. s. 2975-2994. NTNU

Panthi, Krishna Kanta; Basnet, Chhatra Bahadur.
Fluid Flow and Leakage Assessment Through an Unlined/Shotcrete Lined Pressure Tunnel: A Case from Nepal Himalaya. Rock Mechanics and Rock Engineering 2021 ;Volum 54. s. 1687-1705. NTNU

Selen, Lena; Panthi, Krishna Kanta; Vergara, Maximiliano R.; Mørk, Mai Britt Engeness.
Investigation on the Effect of Cyclic Moisture Change on Rock Swelling in Hydropower Water Tunnels. Rock Mechanics and Rock Engineering 2021 ;Volum 54. s. 463-476. NTNU

Ødegaard, Henki; Nilsen, Bjørn.
Rock Stress Measurements for Unlined Pressure Tunnels: A True Triaxial Laboratory Experiment to Investigate the Ability of a Simplified Hydraulic Jacking Test to Assess Fracture Normal Stress. Rock Mechanics and Rock Engineering 2021 ;Volum 54. s. 2995-3015. NTNU

Level 1 papers (high level)

Acharya, Nirmal; Gautam, Saroj; Chitrakar, Sailesh; Trivedi, Chirag; Dahlhaug, Ole Gunnar.
Leakage Vortex Progression through a Guide Vane's Clearance Gap and the Resulting Pressure Fluctuation in a Francis Turbine. Energies 2021 ;Volum 14.(14) s. -NTNU

Alfredsen, K.; Amundsen, P.-A.; Hahn, L.; Harrison, P.M.; Helland, Ingeborg Palm; Martins, E.G.; Twardek, W.M.; Power, M..
A synoptic history of the development, production and environmental oversight of hydropower in Brazil, Canada, and Norway. Hydrobiologia 2021 ;Volum 849. s. 269-280. NTNU UiT NINA

Bringedal, Amanda Sæbø; Søvikhagen, Anne-Marthe Liaklev; Aasgård, Ellen Krohn; Fleten, Stein-Erik.
Backtesting coordinated hydropower bidding using neural network forecasting. Energy Systems, Springer Verlag 2021 s. - ENERGISINT NTNU

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Pattern Recognition of Inter-Turn Short Circuit Fault in a Synchronous Generator using Magnetic Flux. IEEE transactions on industry applications 2021. NTNU

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Performance Evaluation of Signal Processing Tools Used for Fault Detection of Hydro-generators Operating in Noisy Environments. IEEE transactions on industry applications 2021. NTNU

Havrevoll, Ola Haugen; Vereide, Kaspar; Lia, Leif.
Efficiency of Pressurized Rock Traps for Unlined Hydropower Tunnels. Energies 2021 ;Volum 14.(14) s. - NTNU

Juarez, Ana; Alfredsen, Knut; Stickler, Morten; Adeva Bustos, Ana; Suarez, Rodrigo; Seguin García, Sonia; Hansen, Bendik Kristoffer Torp.
A conflict between traditional flood measures and maintaining river ecosystems? A case study based upon the river Lærdal, Norway. Water 2021 ;Volum 13.(14) s. 1-19. NTNU USN ENERGISINT

Kiplesund, Geir Helge; Hiriyanna Rao Ravindra, Ganesh; Rokstad, Marius Møller; Sigtryggsdottir, Fjola Gudrun.
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Internal hydro- and wind portfolio optimisation in real-time market operations. Renewable Energy 2021 ;Volum 173. s. 675-687. NTNU ENERGISINT

Sundt, Håkon; Alfredsen, Knut; Harby, Atle.
Regionalized linear models for river depth retrieval using 3-band multispectral imagery and green lidar data. Remote Sensing 2021 ;Volum 13.(19) s. 1-22. NTNU ENERGISINT

Szabo-Meszaros, Marcell; Silva, Ana T.; Bærum, Kim Magnus; Baktoft, Henrik; Alfredsen, Knut; Hedger, Richard David; Økland, Finn; Gjelland, Karl Øystein; Fjeldstad, Hans-Petter; Calles, Olle; Forseth, Torbjørn.
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Pérez-Díaz, Juan I.; Belsnes, Michael Martin; Diniz, Andre Luiz.
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Modular Multilevel Converter for Variable Speed Operation of Pumped Storage Hydropower Plants. I: PCIM Europe digital days 2021; International Exhibition and Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management. VDE Verlag GmbH 2021 ISBN 978-3-8007-5515-8. s. 1361-1368. NTNU

Doctoral theses

Bibek Neupane,
Long-term impact on unlined tunnels of hydropower plants due to frequent start/stop sequences. Trondheim: NTNU 2021 (ISBN 978-82-326-5384-3) 143 s. Doctoral theses at NTNU

Livia Ioana Pitorac
Upgrading of Hydropower Plants to Pumped Storage Plants: Tunnel System Hydraulics. Trondheim Doctoral theses at NTNU;2021:352

Ødegaard, Henki.
Rock Stress Estimation for Unlined Pressure Tunnel Design. Trondheim: NTNU Universitetsbiblioteket 2021 (ISBN 978-82-326-6139-8) 151 s. Doctoral theses at NTNU

Tor Inge Reigstad
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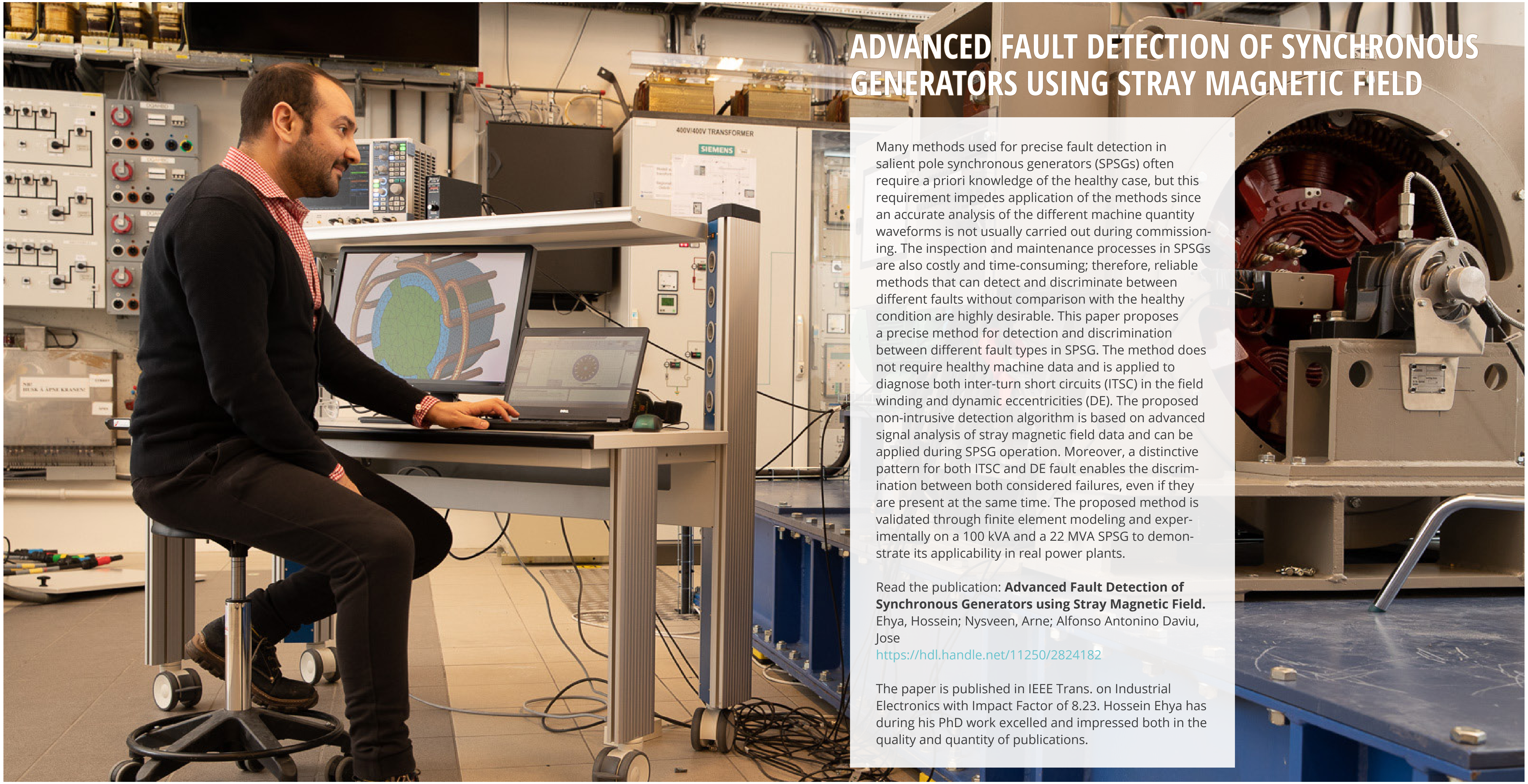
Kristian Sagmo
Trailing edge vortex shedding in hydraulic turbines and the effect of stream-wise vorticity on vortex induced vibrations. Trondheim. Doctoral theses at NTNU;2021:42



ADVANCED FAULT DETECTION OF SYNCHRONOUS GENERATORS USING STRAY MAGNETIC FIELD

Many methods used for precise fault detection in salient pole synchronous generators (SPSGs) often require a priori knowledge of the healthy case, but this requirement impedes application of the methods since an accurate analysis of the different machine quantity waveforms is not usually carried out during commissioning. The inspection and maintenance processes in SPSGs are also costly and time-consuming; therefore, reliable methods that can detect and discriminate between different faults without comparison with the healthy condition are highly desirable. This paper proposes a precise method for detection and discrimination between different fault types in SPSG. The method does not require healthy machine data and is applied to diagnose both inter-turn short circuits (ITSC) in the field winding and dynamic eccentricities (DE). The proposed non-intrusive detection algorithm is based on advanced signal analysis of stray magnetic field data and can be applied during SPSG operation. Moreover, a distinctive pattern for both ITSC and DE fault enables the discrimination between both considered failures, even if they are present at the same time. The proposed method is validated through finite element modeling and experimentally on a 100 kVA and a 22 MVA SPSG to demonstrate its applicability in real power plants.

Read the publication: **Advanced Fault Detection of Synchronous Generators using Stray Magnetic Field.** Ehya, Hossein; Nysveen, Arne; Alfonso Antonino Daviu, Jose
https://hdl.handle.net/11250/2824182

The paper is published in IEEE Trans. on Industrial Electronics with Impact Factor of 8.23. Hossein Ehya has during his PhD work excelled and impressed both in the quality and quantity of publications.

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