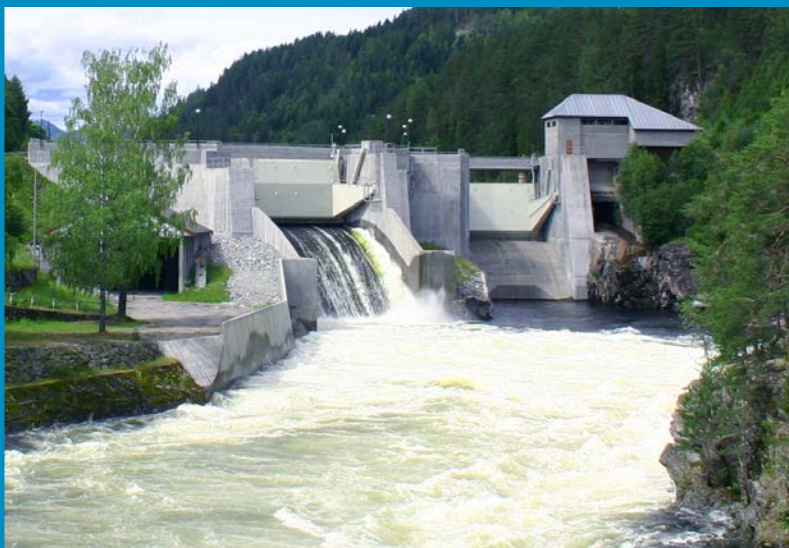
CEDREN

Final Report


CEDREN

Centre for Environmental Design of Renewable Energy

FME

CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

Coverphotos:
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SINTEF NINA NTNU

CEDREN – Centre for Environmental Design of Renewable Energy: Research for technical and environmental development of hydro power, wind power, power line rights-of-way and implementation of environment and energy policy.

SINTEF Energy Research, the Norwegian Institute for Nature Research (NINA) and the Norwegian University of Science and Technology (NTNU) are the main research partners. A number of energy companies, Norwegian and international R&D institutes and universities are partners in the project.

The centre, which is funded by The Research Council of Norway and energy companies, is one of eleven of the scheme Centre for Environment-friendly Energy Research (FME). The FME scheme consists of time-limited research centres which conduct concentrated, focused and long-term research of high international quality in order to solve specific challenges in the field of renewable energy and the environment.

CEDREN Centre for Environmental Design of Renewable Energy

FME Centre for Environment-friendly Energy Research

Content

1 Foreword by the Centre Director

Atle Harby
Centre Director

SINTEF Energy Research

When the Centre for Environmental Design of Renewable Energy (CEDREN) started up in 2009, there were large expectations from all partners as well as the authorities and the Research Council. CEDREN was expected to deliver results from both quite fundamental and from ready-to-use applied research of high international calibre in order to solve specific challenges and from thereby help energy companies, the authorities and the society to meet future challenges.

Environmental design is characterized by multi-disciplinary collaboration and understanding of a range of subjects including technology, engineering, economics, the environment and the society. A fruitful collaboration between skilled scientists, talented students, engaged user partners and stakeholders, has been essential to enable CEDREN to produce internationally recognized research results and valuable innovations. CEDREN has also provided a good dialogue platform through meetings, workshops and seminars.

This final report from CEDREN illustrates important achievements and results from eight years of research in technical and environmental development of hydropower, wind power, transmission lines and the implementation of environmental and energy policy. Further information about the results and activities in CEDREN can be found in scientific articles, books, reports, memos, briefs, annual reports, newsletters and internet articles, all available through the website cedren.no

It has been a great pleasure to work as centre director among highly skilled researchers and students, knowledge-seeking user partners and interested third parties. I am also greatly thankful to the Research Council of Norway and all user partners for the financial support, which has given us a long-term perspective to produce high-quality results and applicable solutions for renewable energy respecting nature.

I hope this report will encourage readers to continue seeking knowledge and dialogue to bring solutions to the challenges we meet within sustainable development and operation of hydropower, wind power and power transmission.

2 Foreword by the host institution

Inge Gran
President

SINTEF Energy Research

The expectations for Centres for Environment-friendly Energy Research (FME) are high. Not only shall they deliver research on a high international level, but also solve challenges in the field of renewable energy and the environment. No less.

I believe CEDREN has lived up to the expectations of the FME-scheme and its' ambition Renewable energy respecting nature. CEDREN have found methods and innovations for optimal design of power lines and hydropower that consider the interest of wildlife, people, as well as the hydropower industry.

Looking back on CEDREN's achievements, I am proud that SINTEF Energy has hosted this centre. I am even more proud of the teamwork in the partnership. CEDREN's purpose is a perfect match to SINTEF's vision, "Technology for a better society." The centre has welded the partners in the centre into a unique team, that will drive the innovation-based research in environmental design in the future.

CEDREN's research has exceeded borders and made a significant international impact, and has become a recognized and visible research community internationally.

I believe that the success of CEDREN in part can be attributed the scope of the FMEs scheme. The size of the scheme lets its' participants from different institutions and the industry delve into a large challenge over eight years. The results are impressive: CEDREN has produced 32 innovations and more than 100 PhDs and Master-students.

Europe is shifting the energy policy towards de-carbonization, and introducing more renewable energy. The research from CEDREN can help Europe achieve its' goals. So CEDREN's legacy will live on in the team platform and the many spin-off projects from the centre – and because the research is more relevant to the world than ever.

3 Summary

CEDREN is a true multi-disciplinary research centre, and all projects and activities are organised with emphasis on bringing several disciplines together, with technologists, economists, ecologists, hydrologists and political scientists joining forces to work towards common goals. The structure of the FME scheme concentrating on "thematic research centres" makes this possible. We strongly believe this would not have been possible in traditionally organised research.

CEDREN has contributed to gain more knowledge in specific fields of research. However, the largest advances in research and contribution to solve challenges related to renewable energy, has clearly been in the interface between traditional disciplines. In addition, the FME scheme also creates a platform of dialogue between scientists and a broad range of end users and stakeholders from industry, authorities and the public. We have experienced that meetings, workshops and seminars organised by CEDREN, creates an open atmosphere where parties that may have contrasting views can meet for information exchange, discussion and positive dialogue.

Before CEDREN started, the strategic vision for future energy policy in Norway did not emphasize the role of hydropower as an important part of future technology. After eight years of research on environmental design of renewable energy, the attitude towards hydropower has changed. Hydropower and flexible energy systems are now given top priority, and the need for ecological and environmental design of renewables is clearly stated by the updated Norwegian Energi21 research strategy. The concept of environmental design of hydropower is in wide use by the industry and the authorities.

CEDREN has developed new and innovative solutions for hydropower technology to meet future demands for more flexible operation and increased need for balancing and storage in the electricity system. At the same time, CEDREN has developed methods, models and guidelines to assess environmental impacts and to find win-win solutions for hydropower production and the ecosystem – successfully implemented as environmental design of hydropower.

The term environmental design has been established and demonstrated not only for hydropower but also for wind power and power lines. CEDREN has developed methods and ready-to-use tools to find the most optimal routing of power transmission lines taking technical, economic, environmental and societal factors into consideration. Through new tools and methods developed in CEDREN, siting and operation of wind power plants can be better adapted to the environment, avoiding conflicts between wildlife and energy production.

One of the main tasks in CEDREN has been to educate PhD, post docs and MSc students. About 30 PhD and post docs and around 100 master students have done their thesis in a broad spectre of CEDREN topics. These candidates are now well suited to serve industry, academia and authorities in future challenges in renewable energy. A lot of the research achievements and results from CEDREN are now used in lectures and special courses at various topics at several study programmes at NTNU.

CEDREN has produced results ranging from fundamental research findings and new theoretical explanations, to computer model development and application of new methods. In-depth research in specific topics have helped understand how river-bed shear stress and lift forces work when discharge changes rapidly, how environmental conditions such as physical habitat, water temperature, ice conditions and water flow influence the growth and survival of young salmonids, and how power line corridors can be maintained to create important grazing areas for moose. These and many more examples of fundamental research all contribute to the wider understanding of the complex challenge to improve environmental conditions at the same time as increasing or maintaining the power production. CEDREN has used such new findings together with existing knowledge and international literature to systematically develop methods, models and guidelines for application, implementation and a broad use of science. This is demonstrated widely in CEDREN, for example in:

- Tools for consensus based siting of wind power plants and powerlines
- Tools to calculate discharge in ungauged rivers
- Models to study how salmon populations are affected by river regulation and climate change
- Guidance in how to make decision-making processes for renewable energy better
- How to compare environmental impacts from different renewable energy sources

The above list is just showing a few of the applied results from CEDREN. Many of these results have been used in case studies, mostly in close collaboration with user partners, describing case studies as the best way of learning and implementing new methods, models and research results.

CEDREN has met with individual user partners 56 times, and the authorities 18 times throughout the project-period. Targeting academia and the scientific community, industry, authorities, stakeholders and the wider public, communication and dissemination have been a central part of CEDREN. This has resulted in:

- 170 scientific publications and more than 500 conference presentations
- Results communicated as reports, briefs, memos, books, handbooks and booklets in order to reach target groups outside the scientific community
- The "Handbook for environmental design in regulated salmon rivers" which gives direct advice for users, and is translated to English and Chinese
- Five textbooks summarizing and illustrating results using a popular science language very well received among end users
- That CEDREN results and knowledge have been exposed in the media in more than 1 000 articles.

Being a research centre has also made it easier to obtain funding and support for laboratory infrastructure and instrumentation for field work to be used by students and researchers in CEDREN. Updated laboratories and modern instruments for field work are crucial to perform in-depth and high-quality experiments and research, and for attracting excellent students and researchers to CEDREN.

32 specific innovations have been identified, ranging from an elevated perch for eagle owls to avoid electrocution, to laser scanning of tunnels and rock caverns - from new models to study energy storage by pumped hydro, to a methodology describing how to obtain environmental adapted hydropeaking.

CEDREN has been very visible internationally and the concept of thematic research centres has been highly appreciated and recognized as an excellent platform to increase international collaboration. In all projects, CEDREN has collaborated with internationally recognised research groups. A research centre offers a good platform to organise international activities, and CEDREN has hosted, organised or co-organised seminars, workshops and meetings in China, Ethiopia, France, Germany, India, Netherlands, Romania, Tanzania, Turkey, Uganda, USA and UK.

The research groups at SINTEF Energi, NINA and NTNU are all engaged in advancing the research and bringing new methods, models and solutions for environmental design of renewable energy further in the coming years.

4 Sammendrag

CEDREN er et tverrfaglig forskningssenter der alle prosjektene og aktivitetene er organisert med fokus på samarbeid mellom ulike fagfelt. Teknologer, økologer, økonomer, hydrologer og samfunnsvitere jobber sammen mot felles mål. FME-strukturen med tematiske forskningssentre gjør dette mulig, i motsetning til hva som ofte er tilfelle innen rammene av tradisjonelt organisert forskning.

CEDREN har bidratt til mer kunnskap innen spesifikke kunnskapsfelt, men de største forskningsmessige framskrittene og de viktigste løsningene på utfordringer innen fornybar energi har blitt funnet i møtepunktet mellom de tradisjonelle fagfeltene. FME-strukturen skaper dessuten en plattform for dialog mellom forskere, industri, myndigheter og andre interessenter. Vi har erfart at møter, workshoper og seminarer organisert av CEDREN skaper en åpen atmosfære hvor de ulike partene, som kan motstridende syn, kan møtes for informasjonsutveksling og dialog.

Før CEDREN startet var det ikke lagt vekt på vannkraft i den norske nasjonale strategien for framtidige energiløsninger. Etter åtte år med forskning på miljødesign av fornybar energi har holdningene til vannkraft endret seg. Vannkraft og fleksible energisystemer har nå høy prioritet, og behovet for miljødesign av fornybar energi er tydelig uttrykt i den oppdaterte forskningsstrategien Energi21. Konseptet miljødesign av vannkraft brukes i stor grad av både industri og myndigheter.

CEDREN har utviklet nye og innovative løsninger for vannkraftteknologi for å møte framtidige krav til mer fleksibel drift og økt behov for balansekraft og lagring i elektrisitetssystemet. Samtidig har CEDREN utviklet metoder, modeller og retningslinjer for vurdering av miljøkonsekvenser og for å finne vinn-vinn løsninger for vannkraftproduksjon og økosystem – realisert som miljødesign av vannkraft.

Begrepet miljødesign har ikke bare blitt etablert og tatt i bruk for vannkraft, men også for vindkraft og kraftledninger. CEDREN har utviklet metoder og verktøy for å finne de mest optimale traseene for kraftledninger ved å ta hensyn til tekniske, økonomiske, miljømessige og samfunnsmessige perspektiver. Gjennom nye verktøy og metoder utviklet i CEDREN, kan plassering og drift av vindkraftverk bedre tilpasses miljøet, og man kan redusere konflikter mellom naturhensyn og energiproduksjon.

En av hovedoppgavene i CEDREN har vært å utdanne doktorgradsstipendiater, post doktorer og masterstudenter. Rundt regnet 30 doktorgrader og post doktorer og omtrent 100 masterstudenter har skrevet oppgavene sine om et bredt spekter av CEDREN-tema. Disse tar med seg kunnskapen til industri, akademia og myndigheter for å bidra til å løse framtidige utfordringer innen fornybar energi. Mye av kunnskapen fra CEDREN blir brukt i forelesninger og kurs i ulike tema ved flere studieprogram ved NTNU.

CEDREN har produsert resultater som spenner fra grunnleggende forskning og nye teoretiske modeller, til utvikling av datamodeller og bruk av nye metoder. Dyptgripende forskning innen spesifikke emner har bidratt til forståelse av hvordan raske endringer i vannstand kan påvirke dekklaget i elvebunnen, hvordan miljøfaktorer som fysisk habitat, vanntemperatur, isforhold og strømningsforhold påvirker vekst og overlevelse av laksefisk og hvordan kraftkorridorer kan vedlikeholdes som viktige beiteområder for elg. Disse, og mange andre eksempler på grunnleggende forskning, bidrar alle til en bredere forståelse av hvordan man kan forbedre miljøforholdene og samtidig opprettholde eller øke kraftproduksjonen. CEDREN har brukt slik ny kunnskap sammen med eksisterende kunnskap og internasjonal litteratur til systematisk å utvikle modeller, metoder og retningslinjer med et bredt bruksområde.

Eksempler på dette er

- Verktøy for optimal plassering av vindkraftverk og kraftledninger
- Verktøy for å beregne vannføring i uregulerte elver
- Modeller for å studere hvordan laksepopulasjoner påvirkes av kraftutbygging og klimaendring
- Retningslinjer for hvordan en kan gjøre beslutningsprosesser når det gjelder fornybar energi bedre
- Hvordan sammenligne miljøpåvirkning fra ulike energikilder

Eksemplene over viser kun noen få av de anvendte resultatene fra CEDREN. Mange av disse har blitt brukt i casestudier, hovedsakelig i tett samarbeid med brukerpartnere som beskriver casestudier som den beste måten å lære og implementere nye metoder, modeller og forskningsresultater på.

CEDREN har hatt 56 individuelle møter med brukerpartnere, og 18 møter med myndighetene i løpet av prosjektperioden. Kommunikasjon og formidling rettet mot akademia og forskning, industri, myndigheter, interessenter og et bredt publikum har vært prioritert i CEDREN, som blant annet har resultert i:

- 170 vitenskapelige publikasjoner og mer enn 500 konferansepresentasjoner
- Resultater i form av rapporter, notater, "briefs", bøker, håndbøker og hefter for å nå målgrupper utenfor de vitenskapelige fora
- Håndbok for miljødesign i regulerte laksevassdrag, som gir konkrete råd til brukere, og som er oversatt til engelsk og kinesisk
- CEDREN-resultater og kunnskap synliggjort i media i mer enn 1000 artikler

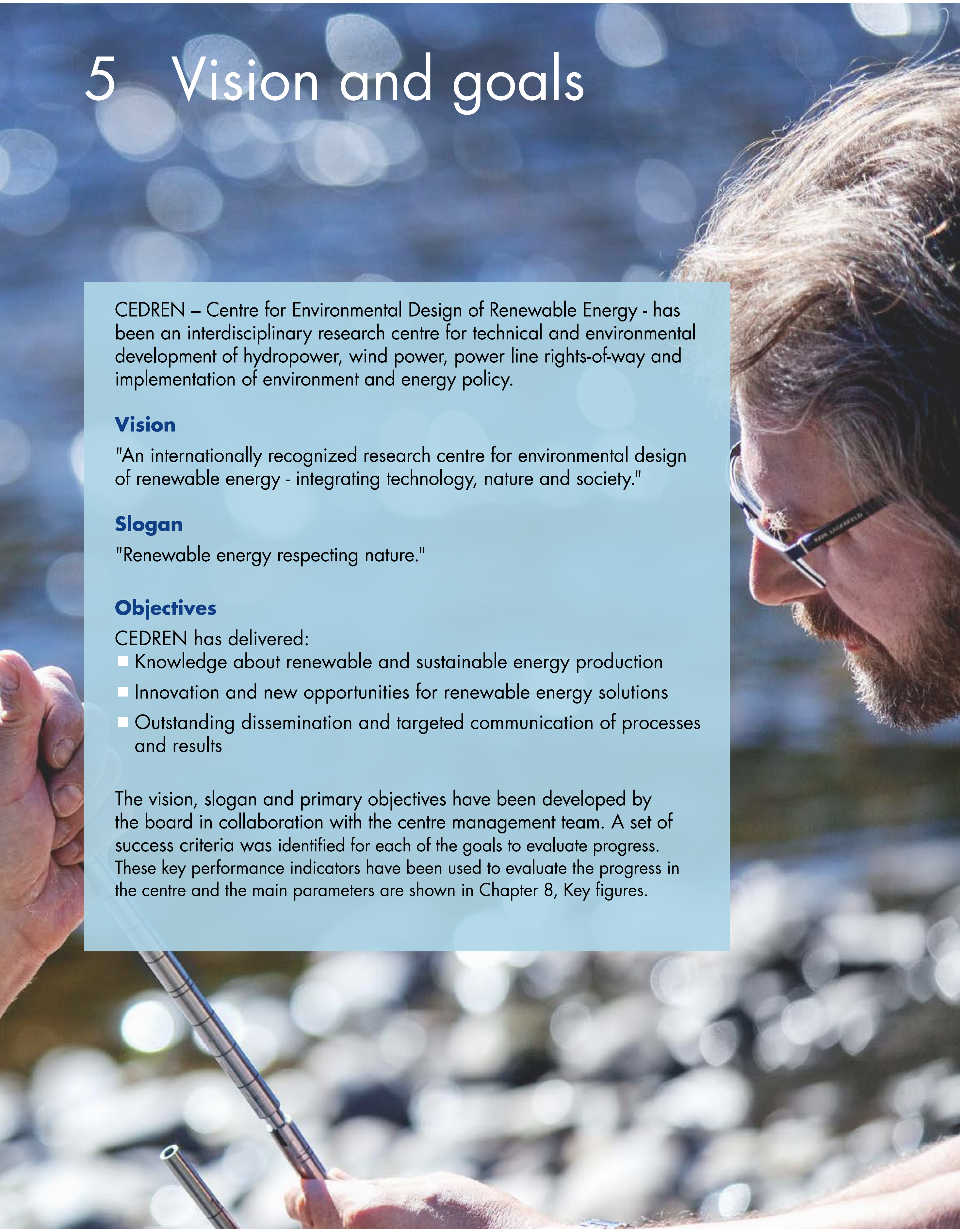
Gjennom å være et forskningssenter, har CEDREN også gjort det enklere å oppnå finansiering av utstyr til laboratorier og feltarbeid til bruk av forskere og studenter. Oppdaterte laboratoriefasiliteter og moderne instrumenter er essensielt for å kunne utføre eksperimenter og forskning av høy kvalitet, og for å tiltrekke seg dyktige studenter og forskere.

Vi har registrert 32 spesifikke innovasjoner, som spenner fra sittepinne for hubro for å unngå dødelige strømstøt fra kraftledninger, til laserskanning av tunneler og steinhuler, fra nye modeller for å studere energilagring ved hjelp av pumpekraft, til metodikk for å beskrive miljøtilpasset effektkjøring.

CEDREN har vært svært synlig internasjonalt, og konseptet med tematiske forskningssentre har blitt satt pris på og anerkjent som en utmerket plattform for å øke internasjonalt samarbeid. CEDREN har samarbeidet med internasjonalt anerkjente forskningsgrupper i alle prosjekter. Et forskningssenter er en god plattform for å organisere internasjonal aktivitet, og CEDREN har organisert og vært med på å organisere seminarer, workshoper og møter i Etiopia, Frankrike, India, Kina, Nederland, Romania, Storbritannia, Tanzania, Tyrkia, Tyskland, Uganda og USA.

Forskningsgruppene ved SNITEF Energi, NINA og NTNU er alle involvert i å drive forskningen framover gjennom nye metoder, modeller og løsninger for miljødesign av fornybar energi i årene framover.

Photo: PK Foto



5 Vision and goals

CEDREN – Centre for Environmental Design of Renewable Energy - has been an interdisciplinary research centre for technical and environmental development of hydropower, wind power, power line rights-of-way and implementation of environment and energy policy.

Vision

"An internationally recognized research centre for environmental design of renewable energy - integrating technology, nature and society."

Slogan

"Renewable energy respecting nature."

Objectives

CEDREN has delivered:

- Knowledge about renewable and sustainable energy production
- Innovation and new opportunities for renewable energy solutions
- Outstanding dissemination and targeted communication of processes and results

The vision, slogan and primary objectives have been developed by the board in collaboration with the centre management team. A set of success criteria was identified for each of the goals to evaluate progress. These key performance indicators have been used to evaluate the progress in the centre and the main parameters are shown in Chapter 8, Key figures.

6 Basic facts

CEDREN (Centre for Environmental Design of Renewable Energy) is an interdisciplinary research centre for technical and environmental development of hydropower, wind power, power line rights-of-way and implementation of environment and energy policy.

SINTEF Energy Research has been the host institution and has been the main research partner together with the Norwegian Institute for Nature Research (NINA) and the Norwegian University of Science and Technology (NTNU).

CEDREN has had a total budget of 422 MNOK for the period 2009 – 2018.
The centre was mainly funded by the Research Council of Norway and energy companies.
CEDREN was part of the scheme Centre for Environment-friendly Energy Research (FME).

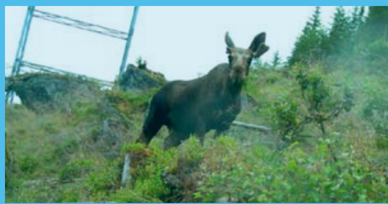
Research activities

The research activities have been organized in the following projects:

- BirdWind: Pre- and post-construction studies of conflicts between birds and wind turbines in coastal Norway
- EnviDORR: Environmentally designed operation of regulated rivers
- EnviPEAK: Environmental impacts of hydropeaking
- HydroPEAK: Integrating the Norwegian hydropower system in the future European power system – Possibilities and Challenges
- GOVREP: Governance for renewable electricity production
- OPTIPOL: Optimal design and routing of power lines in ecological, technical and economic perspectives
- Tools: Tools for integration of environmental design software
- SusGrid: Sustainable grid development
- EcoManage: Improved development and management of energy and water resources
- FutureHydro: Sustainable hydropower development in China and Norway to meet future demands
- HydroBalance: Large-scale balancing and energy storage from Norwegian hydropower
- SafePass: Safe and efficient two-way migration for salmonids and European eel past hydropower structures
- SusWater: Sustainable governance of river basins with hydropower production

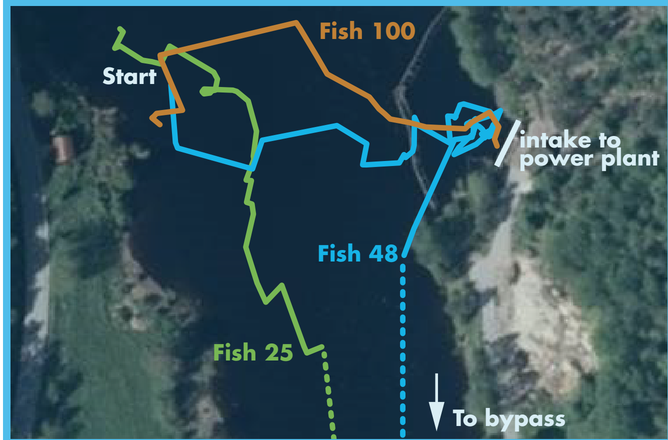
Photos: Fieldwork: Knut Alfredsen, White-tailed Eagle: Espen Lie Dahl, Moose: NINA, Eagle owl: Frode Johansen, Illustration: NINA, Smolt: Ulich Pulg, Excavator: Bjørn Barlaup, Water reservoir: Atle Harby, The Storting building: Stortingsarkivet/ Teigens photoatelier AS, Turbine: Arne Nysveen, Power plant: Ånund Killingtveit, Model of power plant: Kari Dalen, Tonstad power plant: Cedren laser scanner.



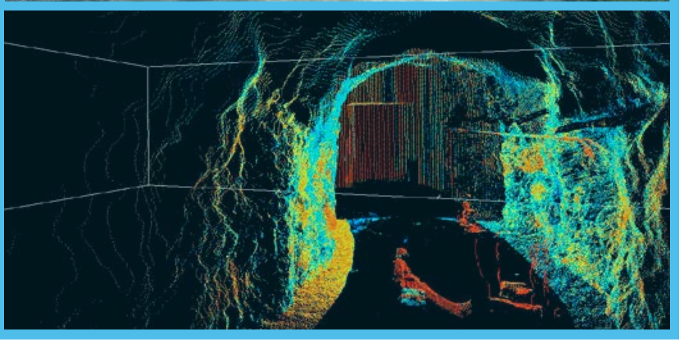







Fish 100
Start
intake to power plant
Fish 48
Fish 25
To bypass





Organisation

The ultimate decision-making body in CEDREN has been the General Assembly (GA) which met once a year. Both user and research partners had a seat and vote in the GA, and the industry representatives in the Board were elected by the GA.

Each main research partner also had a member in the Board, and both the energy and environmental authorities had a seat in the Board. The Board met at least four times per year and worked as an active governing body of CEDREN.

The Centre Director has been responsible for progress and cost control according to approved Working Plans. The Centre Director lead the Centre Management Team and the Centre Management Group. NINA and NTNU each appointed one Vice Director to participate in the Centre Management Team.

Centre Project leaders were managers for Centre projects and members of the Centre Management Group, together with the Centre Management Team and the Centre Manager. The Centre Management Group met once per 1-2 months throughout the whole period, and was the active body to follow up projects as well as discussing strategies.

A Scientific Committee with three international and one national expert was appointed, and has given CEDREN projects and PhD students valuable evaluation of on-going research, obtained results and the way forward.

To ensure a good dialogue with stakeholders, CEDREN established a Reference Group with participants from NGOs, local authorities and organisations interested or involved in renewable energy projects.

The Committee for innovation and implementation has been instrumental to create procedures for identifying, documenting and planning further work for innovations and implementation of new ideas and tools within CEDREN.

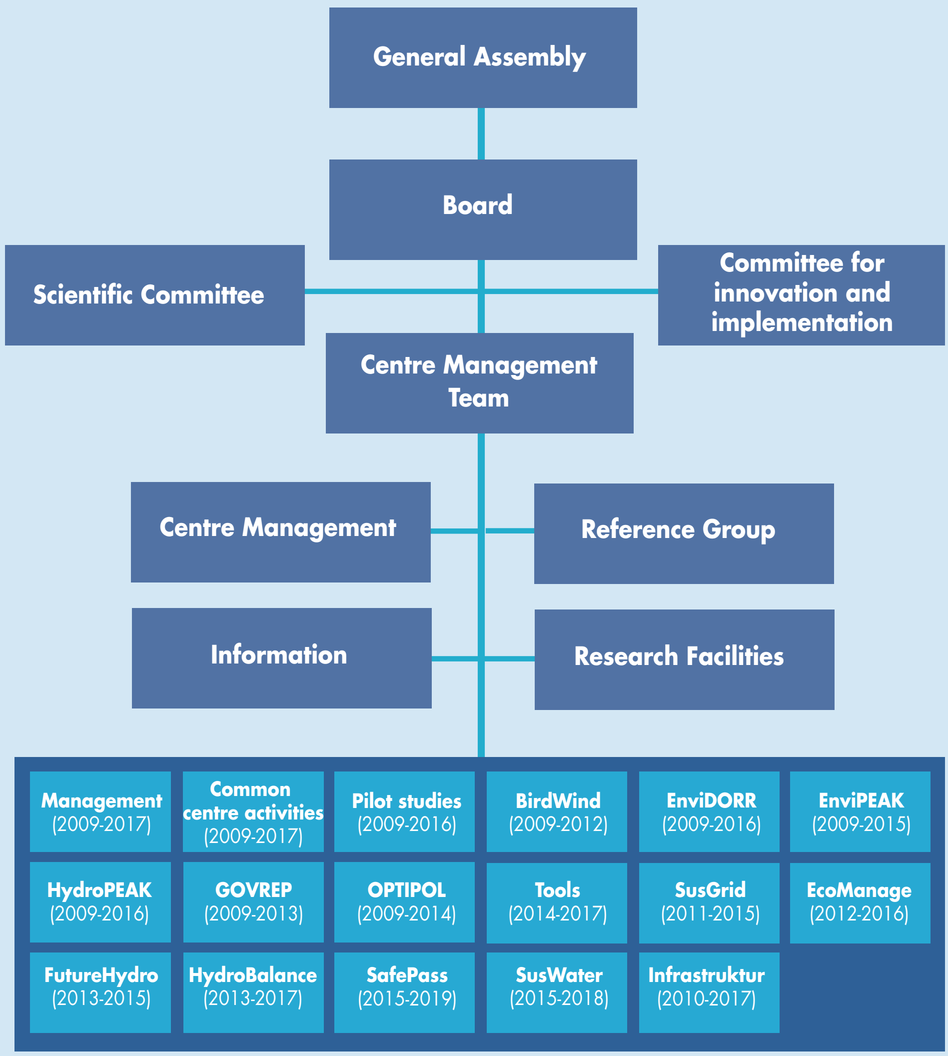
Cooperation within the centre

All together 26 energy companies, Norwegian and international R&D institutes and universities were partners in CEDREN. The partners are listed in Chapter 7. The dialogue and discussion between scientists and user partners has been an important part CEDREN and facilitated through numerous activities like:

- Annual open CEDREN seminars and around 20 special workshops, meetings, seminars and conferences to present and discuss results.
- User groups in each CEDREN project, meeting at least once a year.
- In total 74 special meetings with individual partners.
- Scientific and social events for research partners and students to enhance collaboration within the centre.

The research in CEDREN is based on collaboration between scientists, students and research groups working in technology, engineering, natural and social sciences. This is also reflected in the organisation structure both of the centre management group and in each research project. We believe it is fundamental to work together closely integrated across disciplines to gain real multi-disciplinarity. User groups with engaged participants from the end users have been active for all projects. Each year, the annual CEDREN seminar has been organised to show new results across all projects and activities. CEDREN scientists and project managers have visited end-users in total 74 times, and all user partners have been offered a yearly visit from CEDREN.

CEDREN organisational chart



A complete list of the members of Board, Centre Management Team, Centre Management Group, Committee for innovation and commercialisation, Scientific Committee and Reference Group is given in Appendix 2.

7 Financing

Summary sheet for the main categories of partners (kNOK)

Contributor / Partners		Partner period	Cash	In-kind	Total
RCN 193818 CEDREN FME		2009–2017	80 033	0	80 033
RCN 201779 CEDREN RENERGI		2009–2013	57 695	0	57 695
RCN 178138/177893 BirdWind/EnviDORR		2009	5 200	0	5 200
RCN 207774 SusGrid		2011–2015	9 862	0	9 862
RCN 215934 EcoManage		2012–2016	10 400	0	10 400
RCN 221674 FutureHydro		2012–2015	2 800	0	2 800
RCN 228714 HydroBalance		2013–2017	17 692	0	17 692
RCN 244022 SafePass		2015–2019	14 000	0	14 000
RCN 244050 SusWater		2015–2018	13 000	0	13 000
RCN 197799, 208188, 212706, 226278 Research infrastructure		2010–2017	21 172	0	21 172
SINTEF Energy Research	R	2009–2017	281	25 029	25 310
Norwegian Institute for Nature Research (NINA)	R	2009–2017	238	10 276	10 515
Norwegian University of Science and Technology (NTNU)	R	2009–2017	0	22 571	22 571
University of Oslo (LFI)	R	2009–2017	0	507	507
Norwegian Institute for Water Research (NIVA)	R	2009–2017	0	293	293
Uni Research AS	R	2009–2017	0	2 699	2 699
Agder Energi AS	I	2009–2017	8 895	1 387	10 282
BKK AS	I	2009–2017	3 163	1 252	4 415
E-CO Energi AS	I	2009–2017	6 260	555	6 815
Eidsiva Vannkraft AS	I	2009–2017	4 960	407	5 367
Energy Norway	I	2009–2017	8 598	1 425	10 023
Hydro Energy AS	I	2009–2017	4 300	0	4 300
International Centre for Hydropower (ICH)	I	2009–2017	0	0	0
Sira-Kvina kraftselskap	I	2009–2017	6 372	213	6 585
Statkraft AS	I	2009–2017	45 721	2 724	48 446
Statnett SF	I	2009–2017	6 600	503	7 103
TrønderEnergi Kraft AS	I	2009–2017	1 358	119	1 477
The Norwegian Environment Agency	P	2009–2017	5 515	3 016	8 531
The Norwegian Water Resources and Energy Directorate	P	2009–2017	3 882	173	4 055
Hafslund Nett AS	I	2011–2015	800	24	824
NTE Nett AS	I	2011–2017	800	83	883
Troms Kraft Nett AS	I	2011–2017	380	0	380
Lyse Produksjon AS	I	2014–2017	1 900	127	2 027
SFE Produksjon AS	I	2015–2017	550	68	618
Glommens og Laagens Brukseierforening	I	2015–2017	1 332	466	1 798
Akershus Energi Vannkraft AS	I	2015–2017	300	0	300
Others			4 333	0	4 333
SUM			348 394	73 915	422 309

R - Research partners, I - Industry partners and P - Public partners

8 Key figures

	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total
Scientific publications (peer reviewed)		3	9	14	39	25	30	43	6	**169**
Reports, memoranda, briefs, etc.	2	12	24	34	19	12	11	19	12	**145**
Oral and poster presentations at conferences	7	74	81	104	81	83	28	30	17	**505**
Participation in international committees		2	8	10	4	14	22	13	3	**76**
New and improved methods, models and products				11		3	17			**31**
Articles in international mass media	16	13	6	9	4	3	5	1	4	**61**
Articles in national mass media	55	41	85	47	25	58	42	31	19	**403**
Articles in local mass media	171	7	208	72	20	14	28	14	9	**543**
Dissemination measures for the general public	2	3	7	7	7	6	18	2	3	**55**
Seminars and workshops organised by CEDREN	1	2	7	2	6	4	3	6	3	**34**
Meetings with User Partners	13	8	10	7	4	4	6	7		**59**
Meetings with authorities	1	4	3	5	1	1	3	1	1	**20**
Post-doctoral fellows			1	1		3	1		1	**7**
PhD-degrees completed			2	2		7	3	5	(3)	**22**
Master degrees	2	2	18	21	16	17	16	15	7	**114**

9 Research

The original research plan in CEDREN is built on the common ground of several research projects under the RENERGI programme of the Research Council of Norway.

In the first years of CEDREN, research into hydropower, land-based wind power and transmission lines were not high priority areas in Norwegian research. However, the national strategy "Energi21", soon pointed out the importance of research in many topics related to hydropower and challenges for increasing the flexibility.

Emerging conflicts around wind power and high voltage transmission lines development, soon also lead to more focus on research related to environmental impacts and social acceptance of infrastructure for energy production.

The ideas of Norway as "Europe's green battery" – using Norwegian hydro reservoirs for large-scale balancing and energy storage – also lead to more focus on research in hydropower. This development was initiated by the board, as they started and supported several pilot studies which later was developed into large research projects.

The mid-term evaluation of CEDREN was in general very positive, but pointed out a need to focus more on innovation. Innovations were poorly documented, and the centre management carried out measures to increase the awareness of innovations among scientists and students. We also focused on the implementation of results, solutions, methods and models in the industry and by the authorities, as this also would lead to innovations at the partners. Today, we have documented 32 innovations from CEDREN available for direct use or further developments.

A large part of CEDREN's funding has been research projects under the RENERGI- and ENERGIX-programs at the Research Council of Norway. However, these projects normally last four years, and the mid-term evaluation pointed out the need to increase the funding in order not to decrease the activity in the last three years of CEDREN. This was successfully achieved when in total six ENERGIX-projects have been funded under the CEDREN umbrella.

In the following importent research achievements, highlights of research results and some success stories are presented.

CEDREN publications

In addition to scientific papers, the research has resulted in briefs, memos, books, handbooks and booklets in order to reach target groups outside the scientific community.

CEDREN has documented 32 innovations. Short presentations of each innovation are given in the CEDREN innovation booklet.

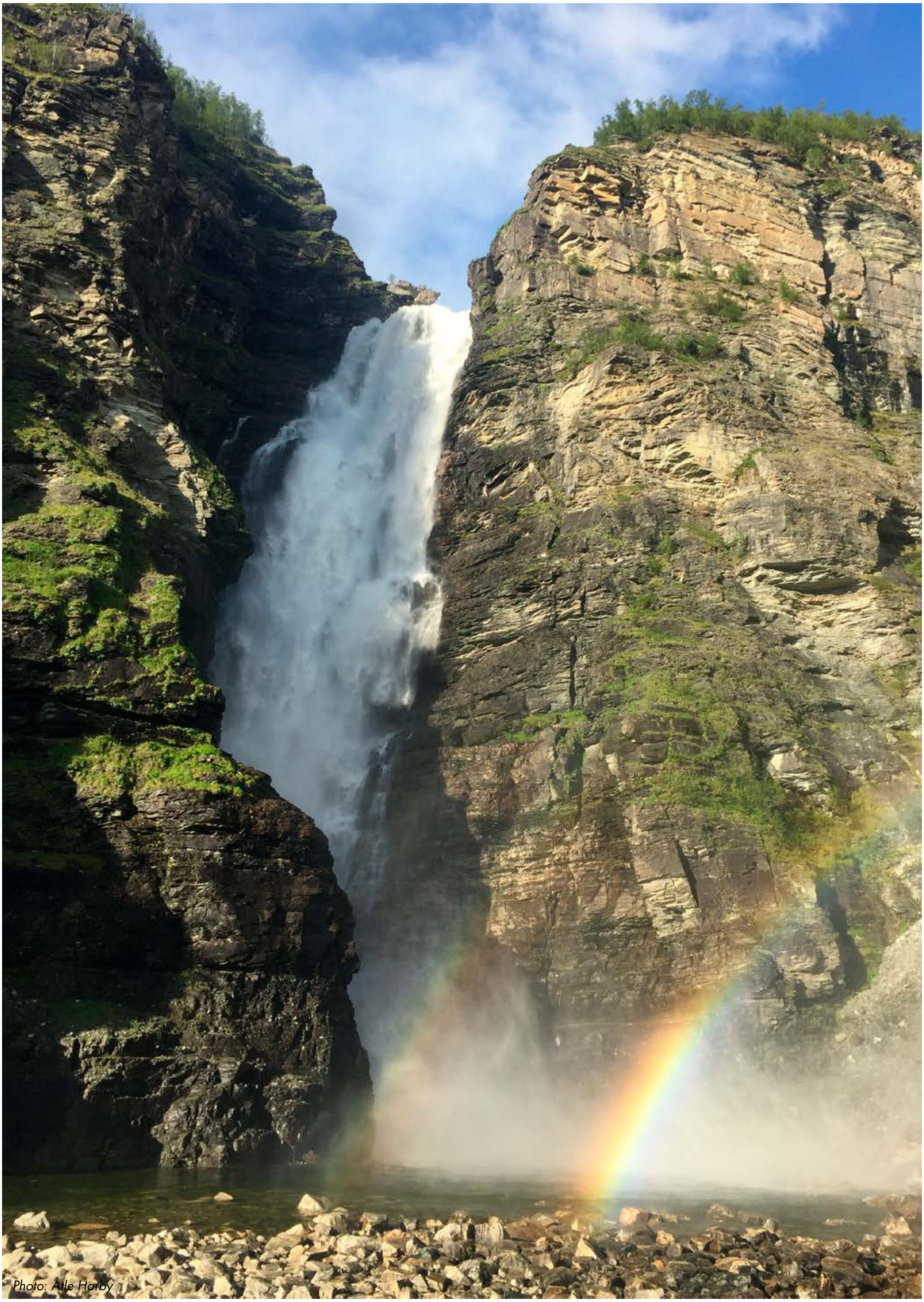


Photo: Atle Harby

Safe elevated perch for the eagle owl

A new design of the power-pole crossarm has made it a safe perching place for the eagle owl.

The eagle owl is the largest owl species in Norway. It has been known for a long time that several specimen dies annually because of electrocution accidents when the birds are landing to perch on power poles, preferably the crossarms of pylons in the 22 kV distribution grid. The eagle owl population has been dwindling for many years, and is categorized as "endangered" at the 2015 Norwegian Red List. The species has its stronghold in coastal areas with high salinity in the air, which is a challenge when it comes to use of conventional isolating materials to cover exposed metallic parts in the pylon to reduce the electrocution hazard. Moist and saline air may create corroding damage underneath the isolating cover.

Corrosion test

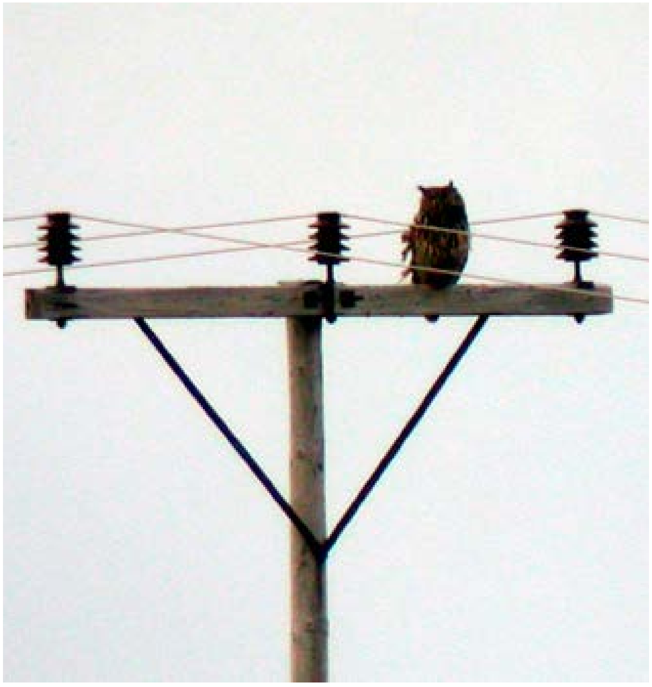
Thus, the main challenges were to develop measures that should prevent the eagle owl from being electrocuted and at the same time prevent the mitigating measure from harming the electrical installation. The study started in the laboratory, were accelerating corrosion tests were conducted to get information on how different types of isolating equipment affect the conductor degradation, i.e. wear and tear, type of corrosion etc., i.e. how insulation could influence the overhead conductor expected life time. It was concluded that covering isolating systems should not be used in exposed coastal areas with a 7-8 marine corrosion index (MCI). Expected lifetime in these environments will be about 10±2 years. Isolation may be used in coastal areas with a 3-4 MCI, as expected lifetime would be 22±6 years. In inland areas with a 0-2 MCI there are no problems with covering insulating systems.

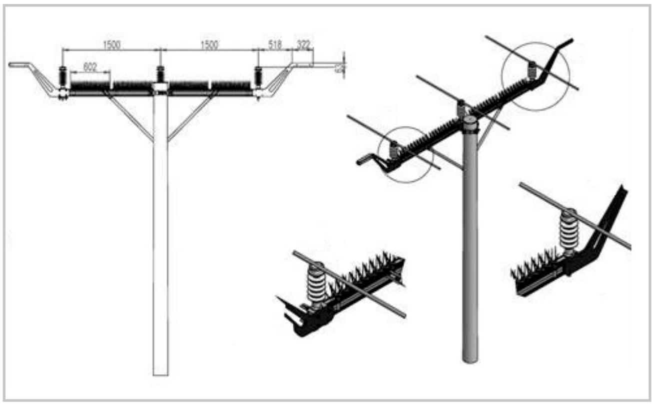
Crossarm redesign

To prevent eagle owl electrocution mortality in coastal areas with a high MCI, it was consequently necessary to develop other types of mitigating measures. A think-tank with CEDREN-researchers and personnel from EL-tjenester AS initiated a process were the aim was to redesign the classic crossarm with pin insulators found in the majority of the 22 kV distribution system. The final product became a prolonged crossarm where the outer prolonged sections were made higher than the rest of the crossarm. At the same time the crossarm area between the pin insulators were covered with a plastic cap with sharp spines preventing birds to sit down.

A win-win solution

A crossarm design making the eagle owl select the elevated parts to perch, will reduce interference problems due to bird electrocution, and the grid owner will experience a more stable supply. The method is a good alternative to conventional isolating equipment. From a technical point of view, it is expected that a correct installation of elevated perch and spike cap, will have no negative impact for the insulators or anything else that can harm the energy system. Definitely a win-win situation for the energy supplier and the bird.





Eagle owls can use poles for perching during hunting. A crossarm design making the eagle owl select the elevated parts to perch, reduces the interference problems due to bird electrocution, and the grid owner will experience a more stable supply.

Photos: Jan Ove Gjershaug

Radar to map bird movements

A bird radar system is expensive to purchase and requires some special skills to use. However, there is nothing like it when it comes to efficient and accurate bird data collection.

The main research activities were carried out on the island of Smøla, providing a better understanding on avian conflicts with wind turbines, and evaluate techniques to do so. To do this a special focus was set on studying known vulnerable model species, one of which was the white-tailed eagle. Apart from mapping wind-turbine induced mortality, data on local and regional movement patterns as well as behavioural responses was important to achieve. The white-tailed eagle is an important species in coastal ecosystems and an attraction to many people. Although being a red-listed species for some years ago, it is now delisted due to a positive population development. It was however, not well received when several observations of eagles colliding with wind turbines were made. To support the study of avian movements within the wind power plant in more detail, its owner Statkraft, funded a bird radar system (Merlin) from the US for the project, which was the first ever to be used for this purpose in Norway. Later on the Research Council of Norway awarded CEDREN an extra grant for infrastructure to purchase a new and improved 3D avian radar system (Robin) from the Netherlands.

Bird data 24 hours a day year around

Human visual observation of birds remains a prerequisite and key method. However, a dedicated radar system is a powerful instrument extending the observation capabilities extensively, in terms of both observation period and the size of the surveillance area. A radar can be set to cover the entire wind-power plant footprint, and can operate 24 hours a day all year round at all types of weather conditions. The Merlin radar gathered data from a horizontal S-band radar and a vertical X-band radar, automatically detecting and tracking birds ('targets') of various sizes on the horizontal plane within a 3.7 km radius circle (2 nautical miles). Flight altitudes up to 5000 m were recorded within a 20 degrees sector with a width of approximately 300 m and a range of 2.8 km (1.5 nautical miles). Automated protocols were developed to handle the vast amounts of data collected from the Merlin radar, as well as good filtering methods for recognizing birds and bird flocks. The radar accuracy was tested using a model aircraft roughly the size of a white-tailed eagle.

Local bird movements and large-scale bird migration

The fine-scale radar recordings of avian movements (i.e. one tracking point every third second) enabled detailed analyses of bird movements and behavioural patterns. Specific white-tailed eagle behaviour, such as thermal soaring could easily be identified. Actual observations of eagles being killed by the rotor blades could also be recognized on the radar. The radar data showed that spring migration activity peaked in April, during the night. The migration was directional towards north to northeast and mainly happened at higher altitudes, i.e. high over the wind power plant. From that point of view, the wind turbines on Smøla did not conflict with migratory species. To support evidence-based consenting decisions, thorough pre-construction studies, using avian radar, can reveal fatal micro-siting of wind turbines responsible for bird fatalities prior to construction. Post-construction monitoring can thereafter ensure comparable data to elucidate any adjustments in flight behaviour and potential collision risk in space and time.

ROBIN mobile avian radar – monitoring bird movements where and when this is required. Photo: Roel May

Modern research equipment contributes to good solutions – the MERLIN Avian Radar System at the Smøla wind power plant. Photo: Roel May

Consensus based siting of wind power plants and powerlines (ConSite)

ConSite is a GIS-based plan- and decision tool suite for optimal siting of wind-power plants and routing of power lines.

Challenge

Renewable energy and transmission grid construction projects often cause environmental impacts, initiate social concern and interest conflicts. This challenges current plan- and decision making practices which has limited abilities to address the inherent scale and complexity of large construction projects. Humans have limited cognitive capabilities to handle large complexities, and decision problems often incorporate a wide range of variables that is overwhelming for manual aggregation or at least subjective to high levels of human error. There is a growing international awareness about this challenge and the societal need for improved plan- and decision support tools that ensure democratic and cost-effective processes securing qualified decision making, transparency and re-examination.

The solution

The ConSite tool suite addresses the challenges and societal needs described above. ConSite is based on current developments in stakeholder dialogue theory, decision theory, multi-criteria analysis, sensitivity analysis and GIS-based Spatial Multi-Criteria Decision Analysis methodology. ConSite helps to structure decision problems, balance conflicting interests and to identify relevant decision strategies based on risk assessment and trade-off analysis. ConSite have capabilities for scenario modelling which helps to predict consequences of applied decision strategies. ConSite is also a project optimalisation tool and offer simple functionality for configuration and layout design of wind power plants. ConSite Wind can be used as a "spatial planning" add-on to existing engineering tools for wind resource assessment, energy yield calculation and wind power plant configuration. At the wind turbine level a fine-resolution GIS-tool for bird-friendly micro-siting is developed, which also can be used as an add-on to existing engineering tools. This tool was developed in the R&D project "Innovative Mitigation Tools for Avian Conflicts with wind Turbines (INTACT)".

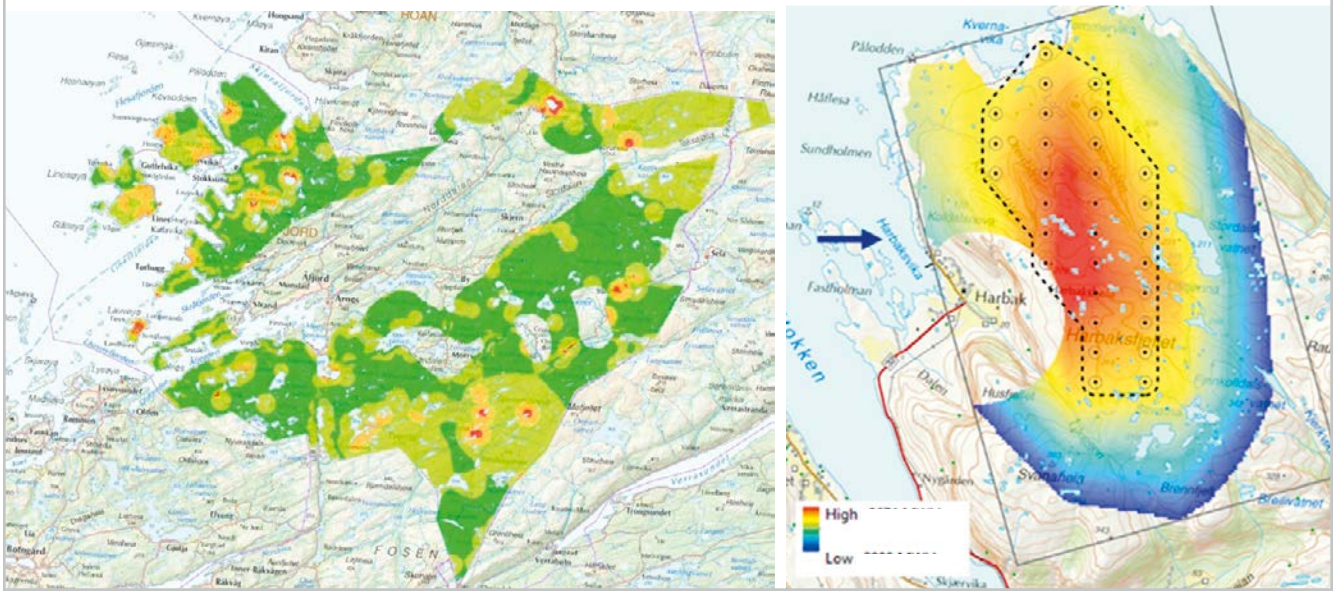
Implementation

There is a growing international interest in ConSite from different sectors such as wind power plant siting, fish farm siting, land-use planning, transport planning and wildlife management. ConSite Wind is now implemented in spatial planning of wind power development in Lithuania. ConSite Powerlines has previously been successfully validated in a power line routing case-study in Sør-Trøndelag.

Potential

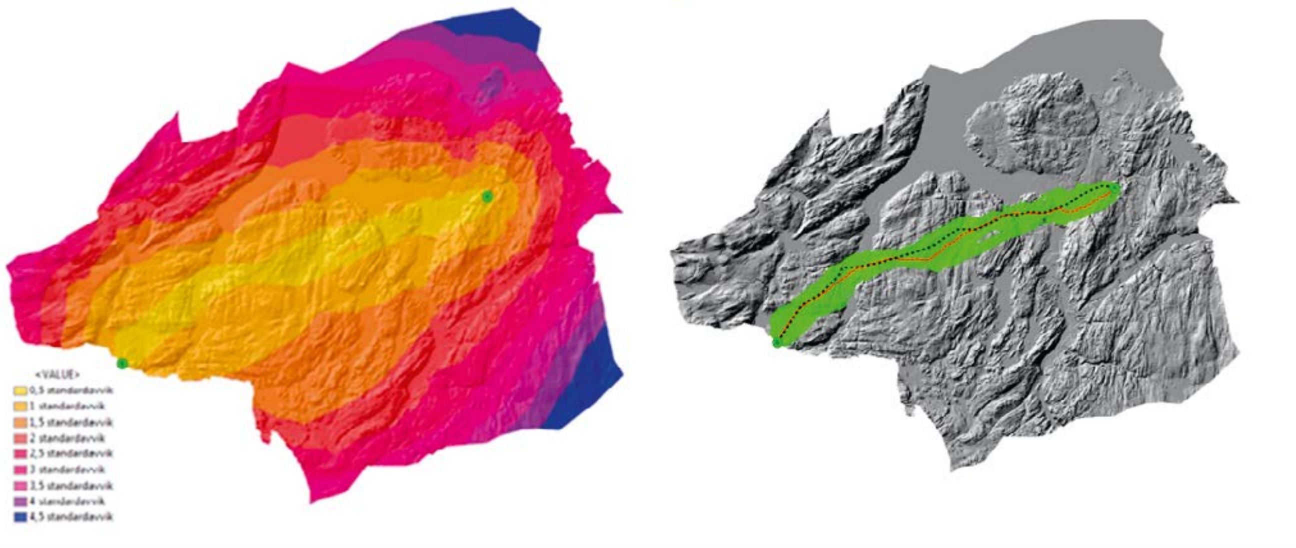
ConSite ensures optimalisation, conflict reduction and re-examination in the pre-construction phase of a wind power plant or Powerline construction project. ConSite has many synergies outside the energy-sector and has been met with great interest from international NGO`s, authorities and companies.

ConSite Wind



Example from ConSite Wind: The Conflict zone map (left map) and required information on wind speed/direction, area size and production estimates are important parameters in the initial wind power plant siting and layout design process (right map). This way, ConSite Wind is a useful add-on to professional wind power plant engineering tools on the market.

ConSite Powerlines



Example from ConSite Powerlines: Conflict zone map (left map) and optimalised corridor and power line path (right map) based on equal weighing of ecological, social and technological criteria. The optimal powerline path (red line in the lright map) was calculated in a successful validation of the ConSite Powerline tool against an existing power line path (black dotted line) in the municipalities of Trondheim, Klæbu and Orkdal in Central Norway.

Increased capacity and pumped storage hydropower

Many European countries are increasing the proportion of wind and solar power generation in their electricity supply. Since it is not possible to store energy generated by such renewables, the high and rapid variability in such Variable Renewable Energy Sources increases the need for reserve capacity and energy storage in the grid, in order to compensate for the difference between production and consumption.

Existing hydropower reservoirs in Norway have a large potential for such services, within the current regulations regarding highest and lowest regulated water levels. Storage and increased capacity can therefore be developed without the construction of new reservoirs, and at a much lower cost than other storage technologies. In CEDREN, we have investigated the potential and cost for upgrading existing power plants with higher capacity and building new pumped storage plants, limiting the search to existing reservoirs and where power plant outlet would be to the sea or reservoirs. Our studies have been complemented by other similar studies performed by NVE and the results compare well.

Research achievements:

- Overview of the most promising sites for new capacity extension in existing HPP in Norway
- Possible sites for new pumped storage plants in Norway utilizing existing reservoirs
- Typical costs as a function of capacity and type of plant
- Comparison to similar cost data in other countries in Europe

Highlights of scientific results:

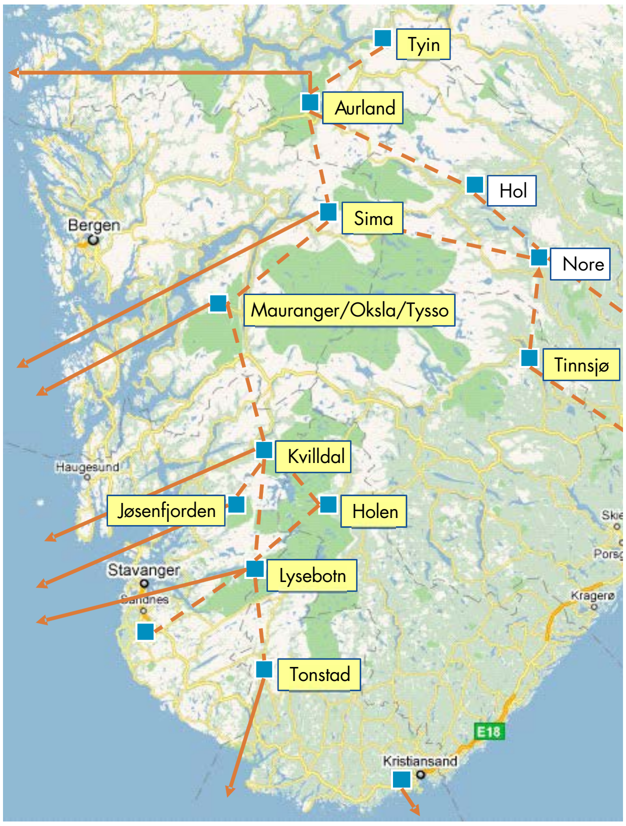
By comparing specific cost (NOK/kW) we have shown that the use of Norwegian hydropower reservoirs is the most economical way to provide storage of large quantities (grid scale) of renewable energy and capacity for balancing power in Europe, since there are already many existing reservoirs that can be utilized. In particular, it will be beneficial to store excess wind power from the North-Sea region on the time-scale of 1-2 weeks. This can be done without compromising the existing use of the reservoirs for seasonal storage of water. The cost of such storage and capacity for balancing power can be lower than for competing technologies, even when the cost of power lines and undersea cables to the Continent and UK are included.

Success stories:

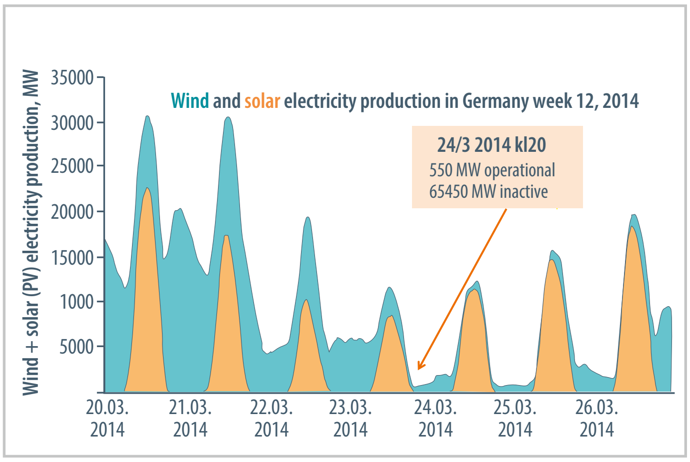
- CEDREN has been leading in the development of the concept "Norway as a green battery for Europe"
- CEDREN has identified and proved the feasibility of developing at least 20 000 MW of new capacity for balancing power with large-scale storage

CEDREN has been active to create cooperation within this topic with Norwegian and European power industry, with the authorities, with NGOs and with scientific partners in Norway and abroad, as far as India and China

The reservoir Vatnedalsvatnet, which could contribute with storage and balancing capacity. Photo: Ånund Killingtveit



Main scenario sites for increasing capacity or new pumped storage plants in South-western Norway



At this time Germany had ca 36 000 MW wind power and ca 30 000 MW solar power (PV). From 23 to 29 March there was not much wind, but good production in the solar power plants (from 7 to 17). When the wind calmed at night 24 March, the total production sank to 550 MW, i.e. a capacity utilization of less than 1 %. At the same time the wind power production in Denmark and other countries around the North sea almost stopped. This illustrates the need for backup and balancing power.

Variable power production in Europe

The EU targets and ambitions for the future power system will include large shares of wind and solar power. However, production from these resources vary with the weather conditions. Since the power demand has to be supplied in every time step, alternative production and storage must supply the load in periods with low production from the renewable resources.

A high temporal and spatial resolution model of wind and solar power production in Europe has been developed in the HydroBalance project. The model is used for analyses of the present and future power system. We used the model to simulate the variability from wind and solar power plants, and to study how the variability can be balanced by use of Norwegian hydropower, demand response and by increasing transmission corridors in Europe. Furthermore, we can use the model to study which combinations of wind and solar power plants will give the least variable production, and how different locations of the power plants will impact the power system. In our view, the model will be useful in national as well as European research projects

High temporal resolution model of wind and radiation resources

The wind and radiation data have a spatial resolution of 7 km x 7 km covering Europe and Northern Africa. The database includes more than 400 000 points for Europe. The data are from the COSMO-EU model, a numerical weather prediction model developed in co-operation between several European countries. Deutscher Wetterdienst (www.dwd.de) gave us access to data for the period 2011-2016.

Correlated weather phenomena

We have used the model to study the variability of the future power production (2050) aggregated for Great Britain, Ireland, France, Germany, BeNeLux, Western Denmark, Switzerland, Austria and the Check Republic. We used installed capacities from the eHighway scenarios (www.e-highway2050.eu). The simulation showed that due to correlated weather phenomena, in some hours there will hardly be any production at all from the wind and solar plants even in that large geographical region.

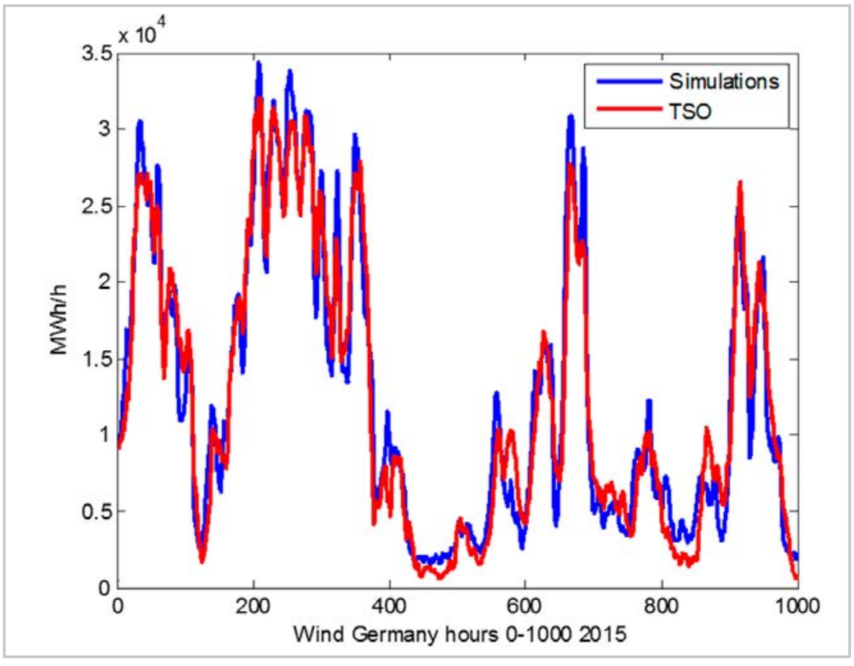


Figure shows validation for the German wind power production in 2015. The blue curve is our simulations of the wind power production based on the wind resources from the COSMO-EU model and information about installed wind power production capacities and their geographical locations from the wind power database (the.windpower.net). The red curve is the real wind power production quantified by the Transmission System Operators (TSO) in Germany.

Wind and solar energy production vary with the weather conditions. Alternative production and storage must supply the load in periods with low production from the renewable resources.
Photo: Emelysjosasen: CC-BY-SA-4.0

Backing up wind and solar power

Based on cost figures from open sources, Norwegian hydropower reservoir provides the cheapest option for backing up wind and solar power when they cannot meet the total demand. By introducing a modification to the widely used concept of Levelized Cost of Energy (LCOE), we developed a new calculation method to include flexibility and the ability to deliver power in peak hours: Levelized Cost of Peak Generation.

We have investigated how Norwegian hydropower can balance variable renewable generation from wind and solar power in Europe. Hydropower represent by far the largest energy storage option in Europe today with about 98 per cent of the installed energy storage capacity. Of this storage capacity, 85 TWh or approximate half of the total capacity is in hydropower reservoirs in Norway. In comparison, the Tesla model S has a battery of 85 kWh. One would need one billion Tesla batteries to get to the same amount of stored energy as in Norwegian hydropower. So balancing from hydropower reservoirs sounds reasonable based on this simple calculation, but does it stand up in a closer examination?

Levelized cost of peak generation

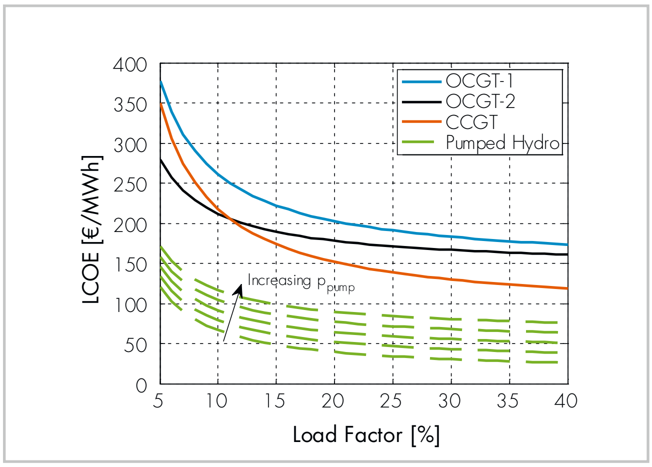
The next step would be to investigate how hydropower would be used if there were a free choice of technology to cover future electricity demand. The traditional approach for cost calculation known as Levelized Cost of Energy (LCOE) is not sufficient for power systems with large shares of variable generation and storage, since it does not tell anything about the flexibility and the ability to deliver power in peak hours. We developed an adjustment to the LCOE method to capture these features: Levelized Cost of Peak Generation. With this method, we have introduced three additional terms to the LCOE:

- We determine the peak hours as the number of hours that variable renewable generation cannot cover the whole load, and use this number as the load factor for all flexible generation technologies and storages
- We determine scenarios for pumping prices (for hydropower) and charging prices (for batteries) to get the full cost of storing energy, also adding the possibility to utilize the storage outside the peak hours
- We subtract possible fixed capacity payments from the costs, e.g. paid by the Transmission System Operator (TSO) to the flexible generator, in order to secure supply

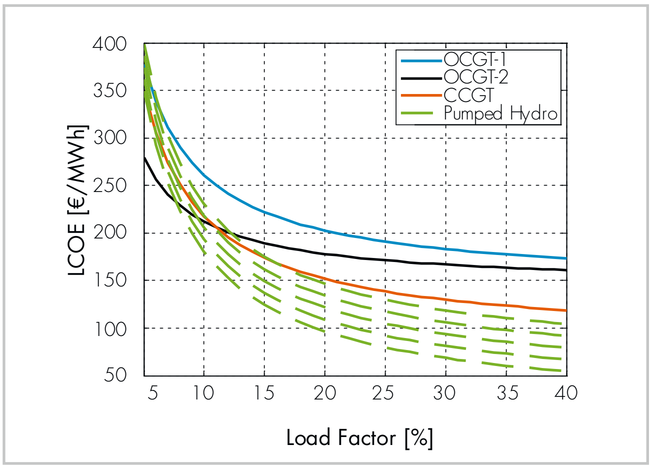
Pumped hydro the best option

With this method, we can compare the cost of alternative technologies for solving the problem of balancing wind and solar generation. We used the new approach to compare pumped hydro storage in Norway to peak production with natural gas power.

Based on cost figures from open sources like IEA, US Department of Energy and IPCC, pumped hydro comes out significantly cheaper than open-cycle gas turbines or combined cycle gas turbines for all realistic pumping prices and load factors of the plants. However, this example omits the infrastructure costs and operating costs of connecting the Norwegian hydropower plants to the continental power system. Assuming that pumped storage alone should pay for the HVDC cables, converter stations and grid reinforcements in both ends of the cable, we re-calculated the comparison. Even under these tough assumptions, pumped storage from Norway is the more competitive alternative as long as pumping can be done when wind and solar generation is high (and prices are low), and the number of peak load hours is not below 10 per cent.



Levelized Cost of Electricity (LCOE), as a function of load factor. Pumped hydro is plotted for average pumping prices of 10 (lowest line), 20, 30, 40 and 50 (upper line) €/MWh.



Levelized Cost of Electricity (LCOE), as a function of load factor. Pumped hydro is plotted for average pumping prices of 10 (lowest line), 20, 30, 40 and 50 (upper line) 50 €/MWh, and includes additional grid and cable costs.

Efficient calculation

So what is the value of this result, besides to show that also when we add more cost elements balancing from Norwegian reservoirs is a possible prospect? This is a fast and efficient calculation method to provide a first picture of relation between competitive technologies. One could do the same calculation with batteries and hydrogen and account for expected technology improvements and cost reductions. If a solution seems robust with this screening method, it can be further analysed using detailed power market simulators.

Efficiency in electricity production

Energy indicators can be used to analyse and compare the energy-efficiency of energy technologies and projects. CEDREN has tested and demonstrated various energy-indicators for a set of Norwegian renewable energy projects, as a support for policy development.

What are energy indicators?

An energy indicator estimates the relationship between the invested energy compared to a certain volume of electricity produced. Energy investments are energy used for the construction and maintenance of infrastructure, energy used for the purpose of extraction of fuel, including processing and transport, and also including conversion losses. Good energy indicators are easy to understand, robust and transparent. A large set of indictors are available, and the individual indicators highlight different aspects of energy production. Energy indicators do not take into account economic costs, or impacts such as loss of biodiversity or green-house gas emissions.

Why measuring energy efficiency?

In a strategic assessment and development of energy resources, a wide set of criteria should be used to find the optimum portfolio of projects, including the energy efficiency of different technologies and individual projects. Energy indicators take a life-cycle perspective, which mean they include all energy use from 'cradle to grave'. As such, they present a complete picture of all energy investments and losses. This will secure a fair comparison across technologies.

Findings from Norwegian energy projects

Until recently, very few Norwegian energy projects have been assessed with respect to their energy efficiency. Studies in CEDREN have documented equally good or better energy efficiency in Norwegian projects compared to international projects. This was found for all indicators used, i.e. energy payback ratio (EPR), net energy ratio (NER) and cumulative energy demand (CED).

Comparison between technologies

Hydropower has far higher energy performance than other technologies, followed by wind power. Electricity production from bio-energy, gas and coal have generally very low energy-efficiency, with bio-energy slightly better than the gas and coal. Refurbishment and extensions of existing hydropower plants have generally extremely high energy efficiency, as large parts of the energy investments have already been made during construction. It should be noted that it can be large individual differences between projects within the same technology.

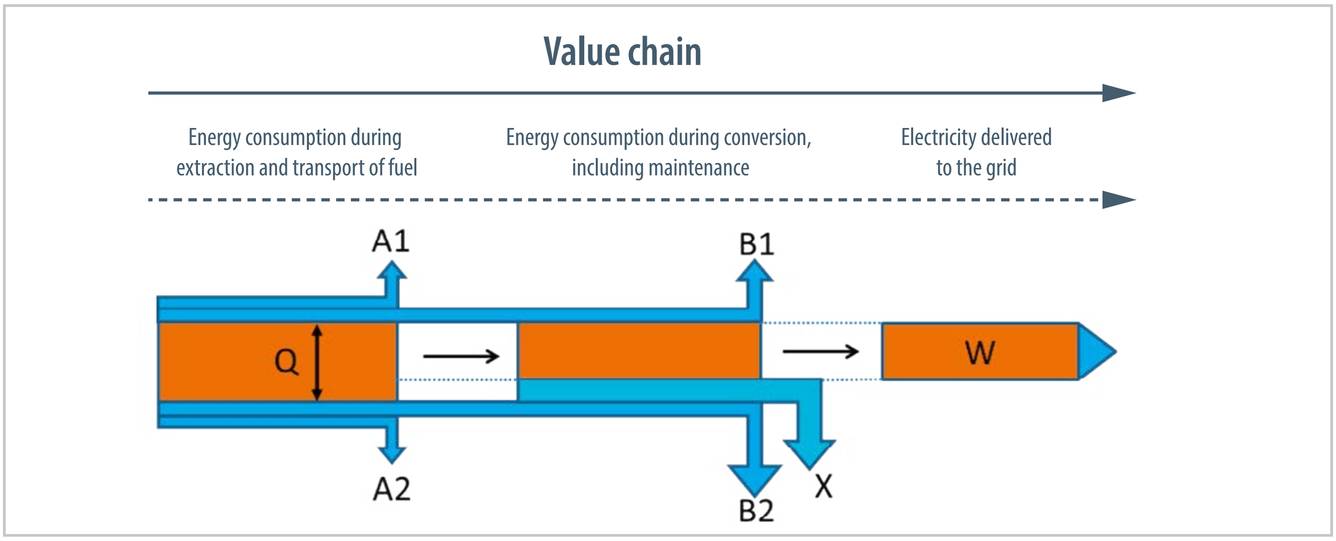
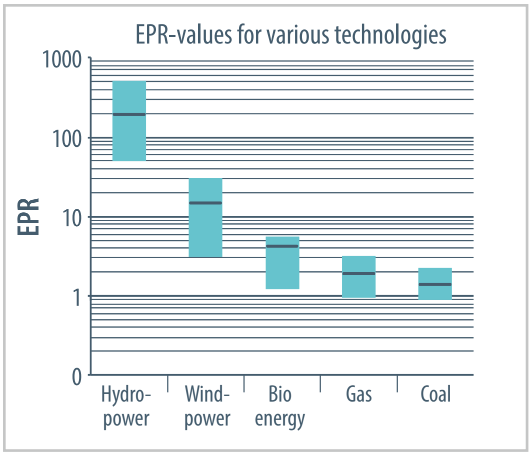
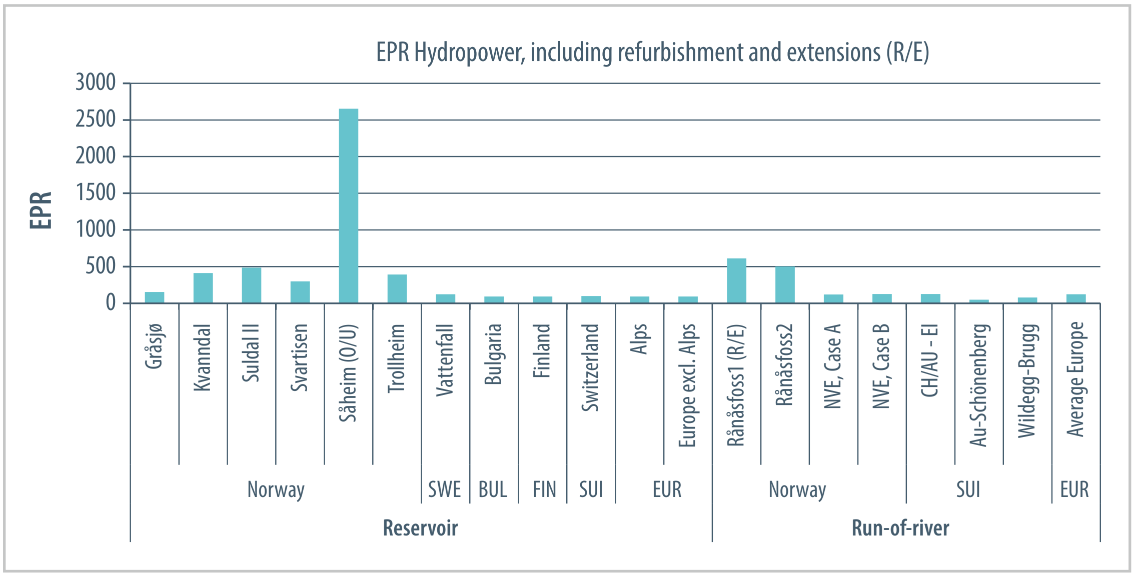


Illustration of the value chain in electricity, where A1 and B1 relate to the energy investments needed to build the infrastructure of the energy extraction site and plant, respectively. A2 relates to the energy use during extraction of the fuel/raw material, processing and transportation, while B2 represents the energy needed for maintaining the energy plant. X is the conversion losses in order to generate electricity. W is the delivered electricity to the grid, out of the originally, embedded energy (Q) in the fuel/raw material.



Comparison of energy payback ratio (EPR) for various technologies, presented in a logarithmic scale. High EPR-values indicate low energy investments compared to the electricity output during the life-time of the energy plant.



Energy payback ratio (EPR) for various reservoir-based and run-of-river hydropower projects located in Norway and the rest of Europe. Due to confidentiality reasons some projects are identified only by their country of location or power producer

Climate change and its impact on hydropower

Renewable energy is an important part of the solution to the global climate challenges facing us in the coming decades. Hydropower is a major source of renewable energy but is also vulnerable to some of the impacts of climate change (CC), since hydropower depends on water resources. Global climate models (GCMs) provide future scenarios for changes in temperature, precipitation and occurrence of extreme weather events, but what do these changes mean in terms of for example river flow, energy generation, dam safety, salmon habitat or ice formation in a regulated river? These are important questions that need answers in order to determine if hydropower is a sustainable energy source also in the future.

Research achievements

CEDREN contribution to climate change research can be clarrified into four main groups:

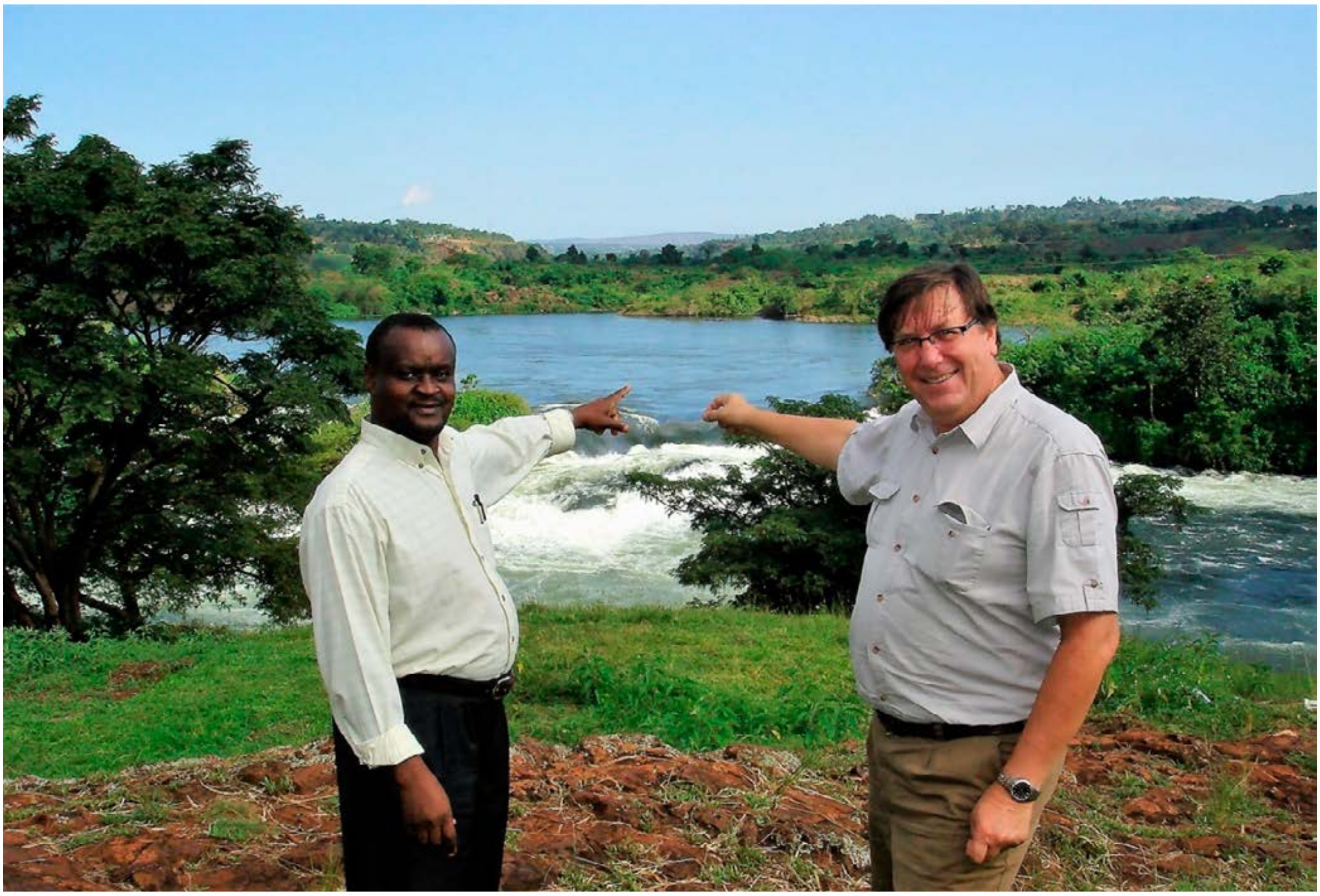
1) Contribution to international working groups on climate change (IPCC, AMAP)
2) Development of tools for modelling and quantification of various types of impacts
3) Studies of climate change and various types of impacts in regulated rivers
4) Capacity building by new PhD and MSc students with expertise in CC-studies

Highlights of scientific results

- Downscaled climate scenarios were used to examine how the changes will affect salmon in the Mandal river
- The first global study about impacts of climate change on hydropower – Paper published in journal Energies and was also used for forming statements in the IPCC Special Report on Renewable Energy report
- Development of a complete set of software and models for use in downloading climate change data, bias correction, hydrological modelling and hydropower modelling
- Impact of climate change on hydropower potential, ice conditions and dam safety in rivers in Norway
- Impact of climate change on hydropower resources in Eastern and Central Africa, including rivers Victoria Nile, Zambezi, Kwanza and Congo
- The methodology and software developed were used for studies of climate change impact on security of supply for the water supply systems in Oslo, Trondheim and Bergen

Success stories

The main findings in CC studies related to hydropower points out an importent role for hydropower in the future energy system, as for mitigatiry climate change effects on water resources.



Climate change may lead to increased available water resources, as here in the Victoria Nile. Professor Felix Mtalo at UDSM and Ånund Killingtveit. Photo: Ånund Killingtveit

Climate change can also lead to less water and problems for water security in some regions. This small reservoir in Tanzania is drying up leaving livestock dying.
Photo: Ånund Killingtveit

Large or small – wind or water?

A CEDREN study has developed a new method for comparison of environmental performance between small-scale hydropower, large hydropower and wind power projects, and compared the environmental impacts.

Comparing environmental performance

Climate change and the needed reductions in the use of fossil fuels call for the development of renewable energy sources, to the cost of reductions in biodiversity and loss of habitats and species. Various national and international policies, such as the EU Renewable Energy Sources Directive (RES), stimulate to increased development of renewable energy production, while for instance the EU Water Framework Directive (WFD) aims at protecting and improving the ecological status in river systems. Finding the right balance between development and protection, and the share of energy projects of various technologies is a challenging task. IPCC has clearly identified the need for tools that support comparison of environmental performance between technologies, and CEDREN has carried out pioneer studies for such types of assessments.

The tool

The tool that was developed makes a comparison of the environmental performance with respect to four different parameters; land occupation, reduction in wilderness areas, visibility and impacts on red-listed species. The basis for comparison was similar energy volumes produced, without considering the quality of the energy services provided. The environmental performance is calculated with use of geographical information systems (GIS) which derive numbers from each energy projects based on thematic maps.

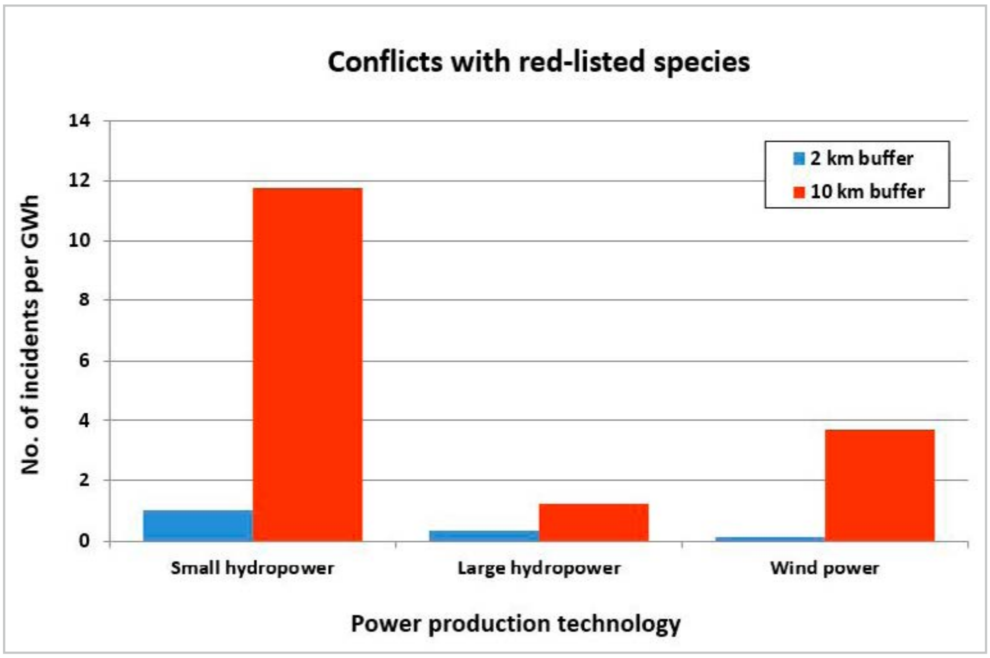
Results

The comparison of a set of small-scale hydropower projects, a few large hydropower projects and a wind power plant shows that small-scale hydropower performs less favourably in all four parameters except land occupation, where the higher land occupation for large hydropower is explained by the extent of the reservoirs. On all the three other parameters small-scale hydropower performs more than two times worse than both large hydropower and wind power. Wind power compares similarly to large-scale hydropower regarding land occupation, much better on the reduction in wilderness areas, and in the same range regarding red-listed species. The results are, however, based on a fairly small dataset and sensitive to the selection of projects.

Prospectives

The tool can be used by authorities to develop energy and environmental policies. Furthermore, it can be used to assess accumulated impacts from several energy projects within a region.

Comparison of environmental performance between small-scale hydropower, large hydropower and wind power projects. Photo: Ånund Killingtveit, Tor Haakon Bakken, Pål Kvaløy



Results from comparison of conflicts between red-listed species and energy projects. The numbers are calculated by counting the number of observations of red-listed species within the areas of a buffer of size 2 and 10 kms surrounding the power production units, respectively.

Discharge from ungauged basins

In many practical applications of hydrology, the question of finding flows from catchments without measurements is central. What was the flow in the regulated river before the regulation was in place? What is the effect of the small tributary draining into the minimum flow reach of a regulated river? CEDREN has worked on modelling tools to answer these questions by using different techniques for predicting flow in ungauged basins.

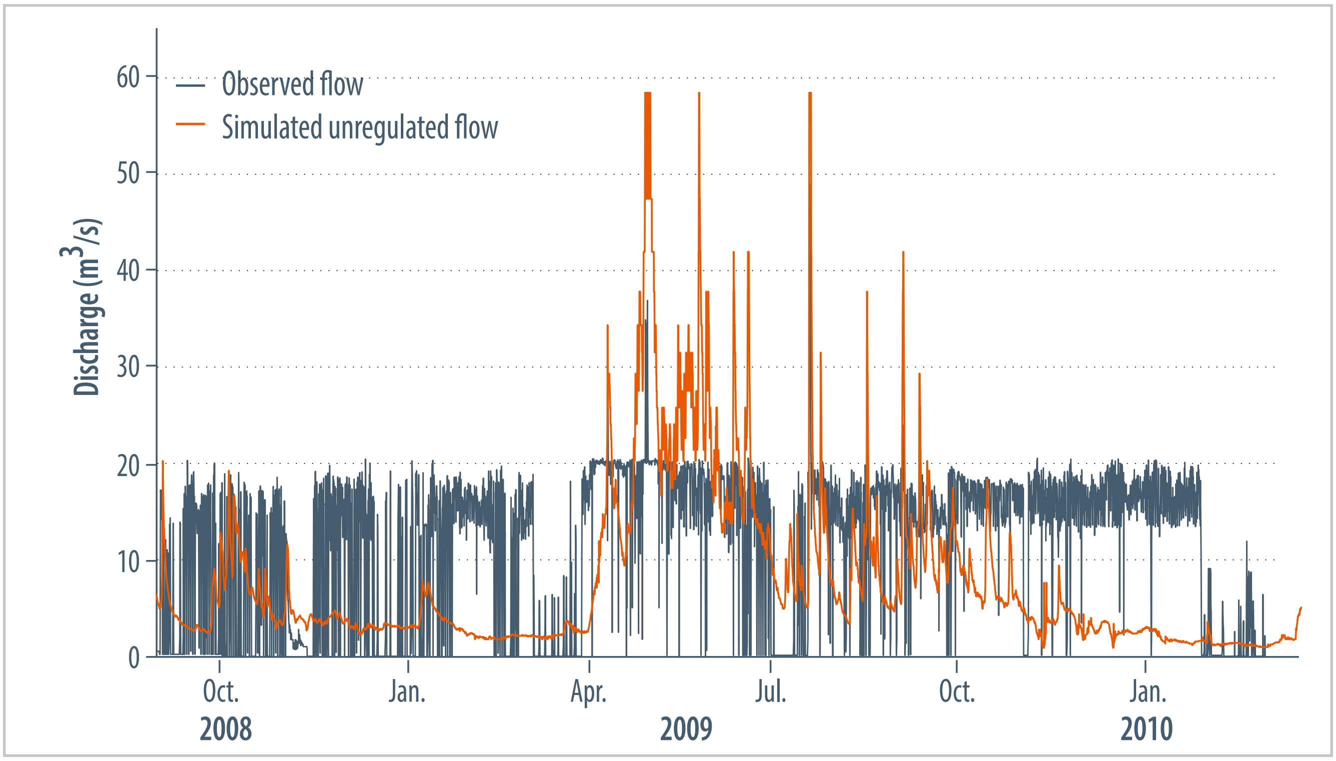
The developed model will be useful in re-licensing processes and in the implementation of the Water Framework Directive. In such cases, there is often a lack of or short data series from before the regulation. To be able to evaluate the effects of the regulation we need to reconstruct the natural conditions to describe pre-regulation conditions which is the starting point for ecological impact assessment and evaluation of mitigation measures.

Models to predict flow in ungauged basins

In CEDREN, we have developed methods to use regional hydrological models to predict flow in ungauged basins. The idea behind the regional model is that we can calibrate a model for a region using several gauged sites within this region. Doing this, the model can then be transferred to another catchment which are ungauged using the common parameter set for the region. Further, methods of mapping quantiles of observed hydrographs to ungauged catchments have been derived. Based on these techniques, we predict both flow before regulation and flow in ungauged catchments. Various implementation of the model has been tested on a number of Norwegian rivers.

As an example, we can look at the river Lundesokna in Sør Trøndelag. This river is regulated and has a production that varies on a sub-daily time scale. There are no data available from before the regulation and to evaluate the effects of the regulation on the flow we need to recreate the natural flow. Here we have done that for the regulated period using the quantile regression method. below is shows the current regulated flow in black and what the natural flow would have been in red for the same period. Based on this, we can continue to compute the relevant parameters describing the effect of the regulation.

To be able to evaluate the effects of the regulation we need to reconstruct the natural conditions to describe pre-regulation conditions which is the starting point for ecological impact analysis and evaluation of mitigation measures.



Powerline corridors – barriers and pastures

Power line corridors may split continuous animal habitats and act as barriers or partial barriers, but can also be attractive pastures. In a biogeographical context, barriers are natural topographic and environmental conditions restricting the natural distribution of some species.

Infrastructure like power lines may affect birds and mammals in several ways. The clear-felled area beneath overhead wires frequently split forested areas creating new habitat types. To what extent power lines or powerline corridors act as barriers or partial barriers, depends on several factors, not at least the target species.

The powerline clear-felled corridor act as a divide between different terrain types and animal resources. A clear-felled corridor in a forest creates an ecotone, i.e. a distinct boundary between a forest and an open landscape. The boundary zone between two types of vegetation differ both qualitatively, quantitatively and physiognomically, and for animals these two types represents different resources with respect to food and shelter.

Modifying clearing routines

Linear structures like power lines and roads are known to affect ungulates like deer, moose and reindeer. We wanted to test how the moose assess power-line corridors. To test the grazing improvement potential, 420 kV transmission line corridor was used as study site. All deciduous trees in a 2.5 km section was cut at about one meters height, while a section (3.6. km) was used as control. Although the data-sampling period was short, the results pointed clearly to a positive food effect for the moose for this clearing regime. In general, a selective logging regime, leaving approximately five meter high trees, secure continuously food access and shelter at the same time. As an alternative to total tree removal the deciduous trees can be cut at about one meters height or half cut, i.e. hinge cut, making the tree to fell over but remain alive. This will shorten the period with poor food access after corridor clearing.

The clear-felled corridor is a moose pasture

The moose did not avoid the clear-felled corridor; on the contrary, the animals frequently used it for grazing and browsing. Quite some time was spent in the clear-felled area and other ecotones, probably because of good food access and better shelter compared to open areas. Transmission lines up to 420 kV have a security zone to each side from the center line of about 20 meters, which in forested areas creates a clear-felled area of about 40 m. Ungulates in forested areas can utilize the grazing and browsing opportunities if the corridor is maintained to offer food and shelter. The impact is particularly significant if the power line cross old growth forests, which may offer poor pastures and browsing opportunities. An obvious conclusion is that the clear-felled areas in connection to the Norwegian power-line grid represents huge grazing and browsing opportunities to the moose population.

Ice research in CEDREN

Ice is a common feature in northern rivers during winter, and ice formation and breakups are complicated processes which influence hydropower operations, ecology and infrastructure within and near rivers. In relatively steep and small rivers in Norway, quantitative measurements of ice formation are not readily available and CEDREN has focused on improving observation techniques and modelling tools of ice processes.

Combining several seasons of field work in rivers measuring climate, ice amounts and the extent of ice with numerical modelling and data analysis we have improved the knowledge of ice formation and the way we can model small stream ice formation. Data collection includes aerial photography from small planes, bankside observations and time lapse photography at critical locations. These data are used to set up and verify a numerical model of river ice which simulates the formation and growth of ice in the river.

Releases of water from reservoirs in winter will influence the ice formation in rivers downstream of the outlets as water temperature in lakes and reservoirs d. By applying the calibrated model, we have quantified the effects of regulation on ice formation in the river Orkla. This shows the prolonged frazil ice generation periods and periods with reduced ice cover after regulation – which in a way gives us less stable surface ice and more ice production after regulation. This can be used to evaluate effects of water releases on ice formation, and has been done in CEDREN to evaluate current regulation permits.

Climate is an important driver for ice formation and long term changes in climate will influence how ice is formed in the future. This can lead to a shorter winter season, and due to higher climate variability also a more unstable winter. A more unstable winter can lead to more winter ice runs, several freeze-up periods and generally more variable conditions in the river. CEDREN used downscaled climate data to evaluate measures of winter length and winter stability to find the future ice regime and how this can influence the winter conditions in lakes and rivers in the future. A part of this work was done in cooperation with a Nordic Centre of Excellence on climate change in cold regions looking at winter and ice formation in the entire Nordic region. We then extended the methods and looked in detail on three different hydropower reservoirs and on the future ice formation in river Orkla.

Dynamic ice model

Together the work within CEDREN has provided several new developments within ice research in Norway. We have tested and found that it is possible to use a dynamic ice model in steep Norwegian streams. This could be a foundation for future analysis of ice. Secondly, we have developed methods and collected data that was missing for analysis of ice formation. Both the data and the methods will be useful in the future. And thirdly, we have evaluated climatic impacts on future ice formation and winter climate in lakes and rivers.

New methodes and tools help hydropower companies manage ice problems.. Photo: Knut Alfredsen

A travelling river bed

Many hydropower plants release water into rivers where the river bed consists of gravel. Due to the fairly constant flow of the hydro power plant release, such gravel-bed rivers will usually have established an armoured stream-bed with coarse gravel at the top layer.

The formation of an armored layer means, that the fine material of the grain size distribution has been washed out from the top layer, and that the coarse material form a certain type of protection for the sub layers below.

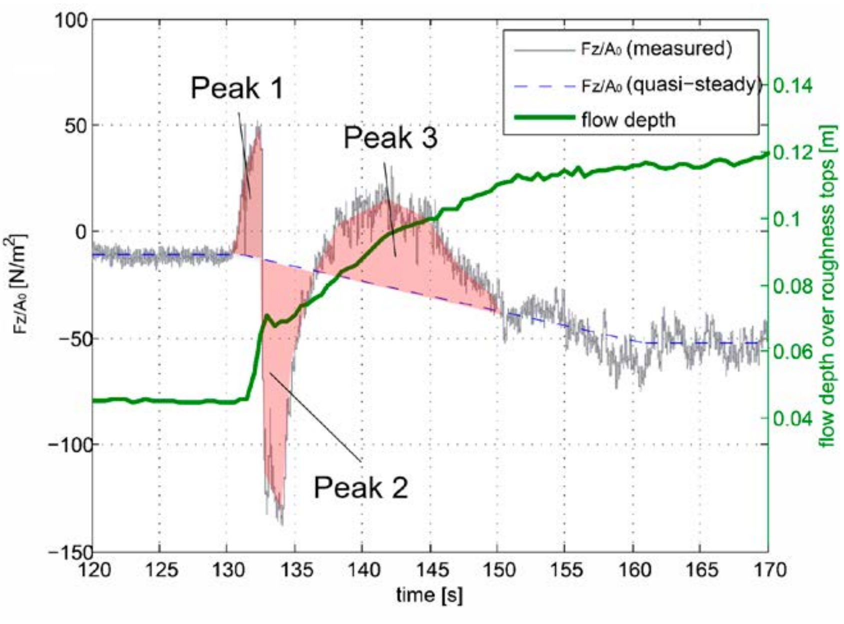
Having this constant flow over a long time, the armour layer gets more and more compacted and can withstand sometimes up to seven times the critical shear stress of the coarsest single grain. The goal of the study was to investigate how far the stability of this armour layer will be influenced when the hydro power plant will shift to peaking operation.

Research achievements:

A technique to artificially reproduce a permanent and very detailed copy of the surface structure of a stream-bedwas developed, and we could thereby perform repeated experiments on flow pattern and forces above an artificial static armour layer. These investigations, conducted under unsteady flow, have focused on (i) bed-shear stress, (ii) dynamic lift on the streambed and (iii) spatial fluctuations in the near-bed velocity field. By creating and using an exact copy of the riverbed it was possible to reproduce experiments in the laboratory many times and even to repeat experiments in other laboratories in order to make independent verification of the results. Such experiments have not previously been possible, since an erosion event will rip up and destroy the original river bed and prevent repeated experiments with exactly the same river bed.

Highlights of scientific results:

Bed-shear stress during unsteady flow could be very well predicted with the St. Venant equation and showed no significant dynamic effects as it consistently increased with increasing discharge. The dynamic lift acting on a patch of the streambed, however, showed remarkable variations in form of three distinct peaks during increasing flow. The following hypothesis regarding spatial velocity fluctuations in the near-bed flow field has been proposed: In uniform flow conditions the form-induced stresses, being an indicator for spatial velocity



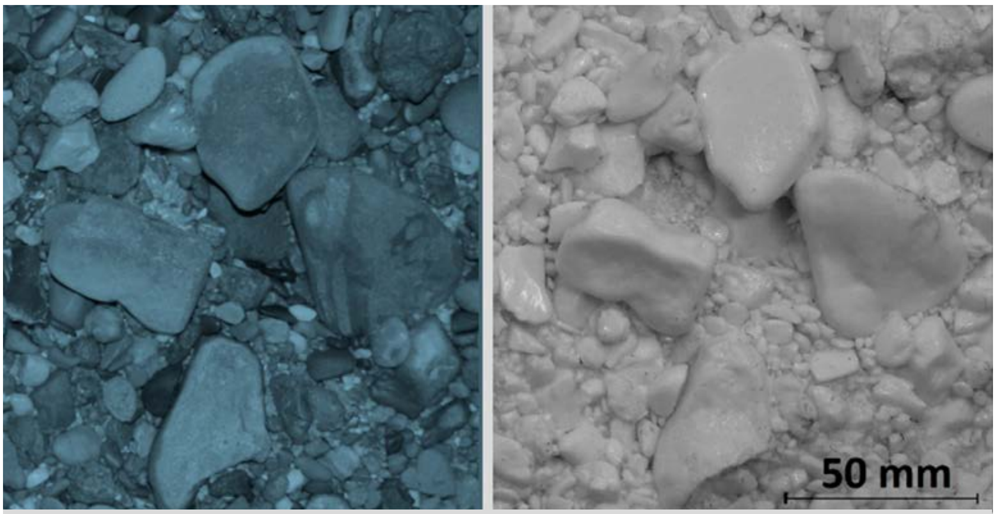
Lifting force on riverbed measured during a rapidly varying flow event. Three distinct peaks can be seen.

Together with Technical University of Braunschweig, Professor Nils Ruther and PhD candidate Stephan Spiller concieved the idea of using an artificial river bed. Here they are holding a section of the artificial river bed used in the experiments.

fluctuations, are independent from the discharge. In non-uniform flow conditions the magnitude of form-induced stresses close to the streambed increases with increasing discharge, while the qualitative shape of the form-induced stress distributions is independent from the discharge and unsteadiness of the flow.

Success stories:

The artificial river bed has been used to perform a large number of experiments in the Hydraulic laboratory in Trondheim, with varying flow and slope. The experiments were done in the new variable-slope flume that was financed by the CEDREN Infrastructure program. In addition, the copy of the river bed was brought to laboratories in Germany and Australia for repeated independent experiments in order to verify the results.



Static armour layer *Artifical copy*

A picture of from a natural river bed (left) and the artificial copy made in composite (right).

Laser-scanning in hydropower tunnels and rock caverns

The waterway is one of the main and most costly parts of a hydropower plant. Excavating tunnels for waterways by rock-blasted is a slower but usually less expensive method for tunneling, compared to utilizing tunnel boring machines (TBM). If the rock is of good quality, such tunnels can also be unlined. However, the variation in cross-section geometry and surface roughness that arises in unlined rock-blasted tunnels results in a considerable increase in friction and head loss which means reduced power generation.

An accurate description of the final geometry of the tunnel serves as a basic and necessary tool for inspection, maintenance work, and optimisation of production. In addition, when combined with a roughness analysis, it allows correct analysis, as well as physical and numerical hydraulic modeling. Therefore any techniques to improve the charting of the geometry of rock-blasted hydro power tunnels are highly valuable. The technique described here not only provides also better evaluation of tunnel roughness.

Research achievements:

In her project, PhD candidate Kari Bråtveit developed a methodology and tested the use of terrestrial laser scanners (TLS) for mapping geometry and surface roughness in tunnels and rock caverns in hydropower plants. She was also able to utilize the much more accurate geometric data from the laser scanning to establish improved hydrodynamic (CFD) models for a section of the tunnel system and sand-trap in Tonstad hydropower plant.

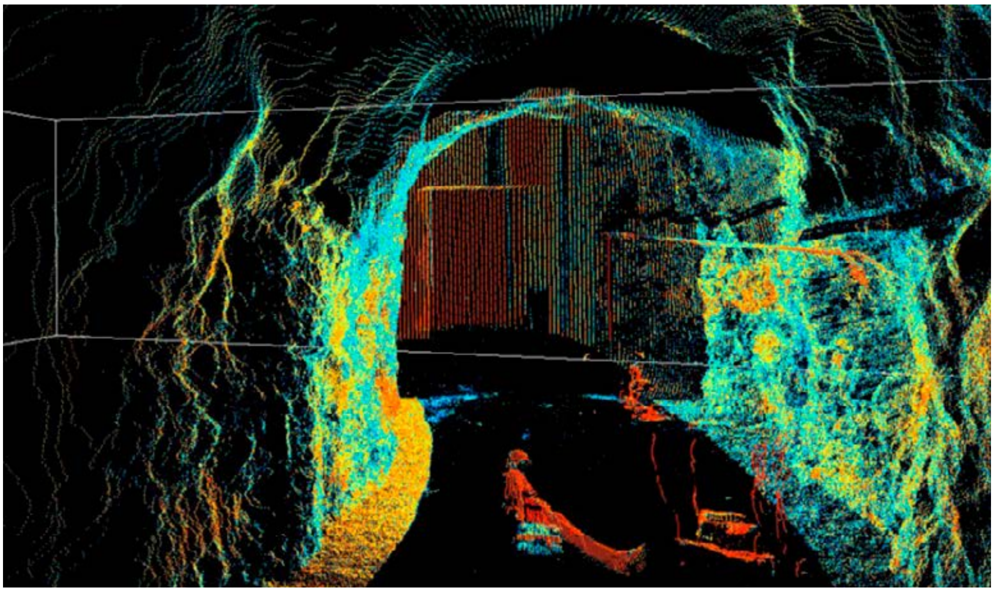
Highlights of scientific results:

- A successful demonstration of the use of laser scanners (TLS) in underground hydropower tunnels
- Setting up a CFD model using geometry data from TLS and verifying the model by Acoustic Doppler Current Profiler (ADCP) measurements from sensors set up and operated from inside the tunnel system
- A new simplified method for computing head-loss in hydropower tunnels ("Bråtveits method")

Success stories:

The numerical model, simulating flow in 3D during both steady and variable flow conditions, could demonstrate the appearance of local high velocity zones which in turn could lead to erosion and transport of material from tunnel bed and sand-trap into penstock and turbines. The model will be used in new studies for Sira-Kvina power company, in order to design a new sand-trap with better performance.

Plot from the CFD model of a tunnel system just upstream the entrance to the penstock. Input data setup was based on TLS data from Tonstad hydropower plant.



Results from laser-scanning in the hydropower tunnel – notice the detailed mapping of rock-face.

Measurement by using TLS in a hydropower tunnel.

Closed surge tanks for hydropower plants

In a typical hydropower plant with a tunnel system of 10 km and a cross section of 50 m^2, 500 000 tons of water, equivalent to ten thousand 50-tons trucks, is in motion towards the power plant. If the power plant suddenly must close down, this large mass of water needs to be stopped in a controlled and safe way, to avoid damage on pipes and turbines. This is the job of the surge tank, a vital element in hydropower plants with a functionality similar to shock absorbers in cars. A Norwegian specialty in surge tanks is the closed surge tank.

The closed surge tank is constructed as an underground cavern filled with pressurized air. During a sudden stop of the turbines, water will flow into the tank. The rising water level will increase compression of the air and create the necessary counter pressure to slow down and stop the water flow.

This solution is particularly attractive for peaking and pumped storage plants because it is independent of a surface access, and can be placed closer to the turbines compared to other types of surge tanks. This type of surge tank may therefore be of interest for future construction of peak power and pumped storage plants in Norway.

Research achievements

In his PhD project Kaspar Vereide managed to combine hydraulic and thermodynamic theory of closed surge tanks in both numerical and physical scale models, also including the tunnel system and hydraulic machinery like turbines. The model results compares well to field measurements from two existing power plants, the 40 MW Jukla pumped storage plant and the 150 MW Torpa hydropower plant.

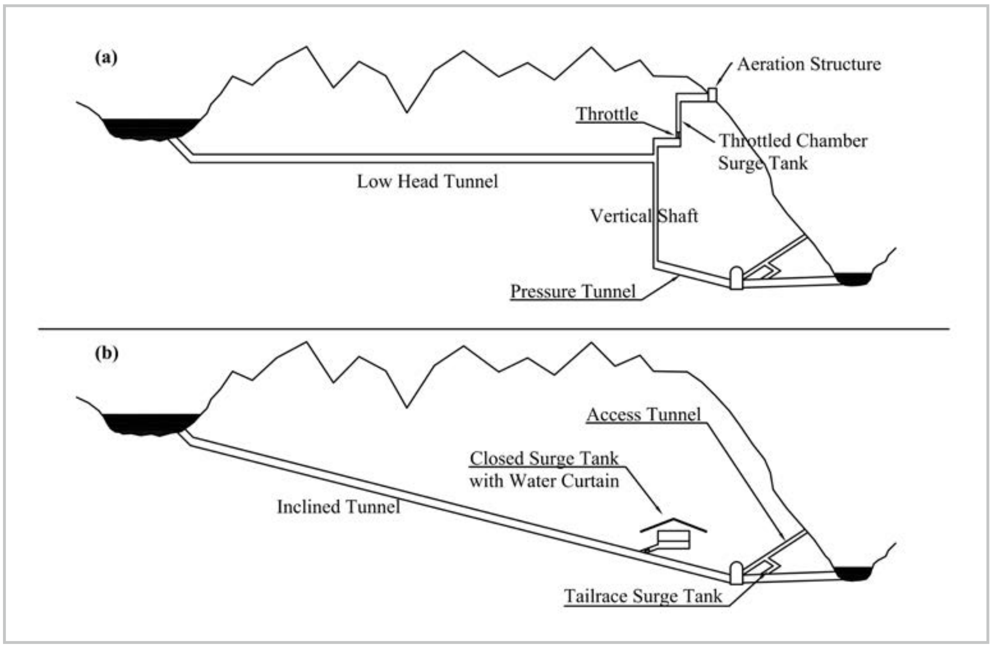
Highlights of scientific results

- An overview of the benefits and challenges of the closed surge tank compared with the open surge tank.
- A new method for scaling hydropower tunnels with closed surge tanks for hydraulic scale model tests.
- An assessment of the accuracy of a hydraulic scale model of a hydropower headrace tunnel with a closed surge tank.
- A modified rational heat transfer (MRHT) method for calculating the thermodynamic behavior in closed surge tanks.
- A methodology for evaluating the effect of surge tank throttling on governor stability and performance in hydropower plants.

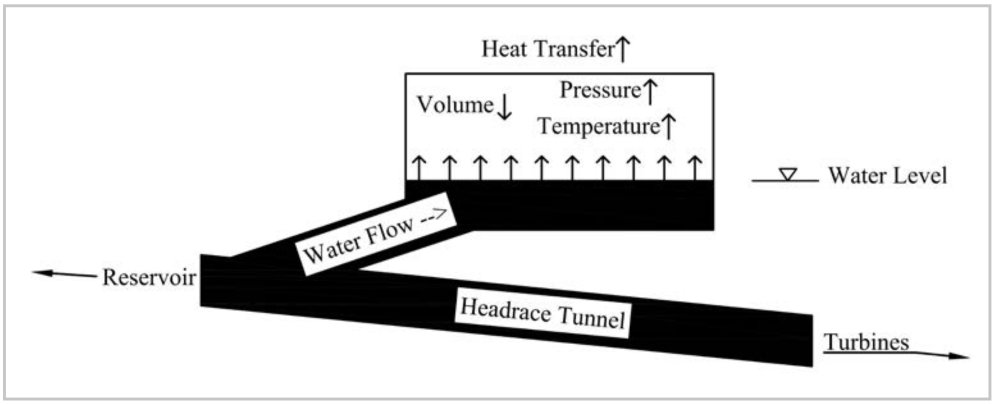
Success story

Kaspar Vereide has cooperated with Multiconsult to design a closed surge tank for the 220 MW hydropower plant Upper Kontum, which is under construction on the river Se San in Vietnam. To make a conventional surge chamber at Upper Kontum, they would have had to build a two hundred meter tall concrete tower on the surface, as the mountain above the power plant is not high enough.

PhD Kaspar Vereide is operating the physical scale model in the Hydraulic laboratory at NTNU.



Typical layout for a high-pressure hydropower plant with a) traditional open surge tank and b) closed tank with air cushion. Notice the more direct route for the headwater and a simplified tunnel system for b) compared to a).



Main parameters in the modelling of a closed surge tank during water inflow. The functionality is similar to an air bag in a car.

Predicting environmental effects in hydropower reservoirs

We have developed a new method to predict how environmental conditions in reservoirs may change under future hydropower operations. The method creates a direct link between the international power market and environmental effects in Norwegian reservoirs. This will be important in order to predict potential changes in the coming years.

Water level fluctuations modify reservoir ecosystems

Water level variations is the main hydropower impact in reservoirs. We have predicted that future operational regimes with more flexible hydropower may lead to changes in the yearly, seasonal and daily fluctuations in the water levels. Fluctuations in water level will affect the physical properties of the reservoirs, such as temperature, ice-cover, erosion and mixing of water, which in turn will change the living conditions for fish and other species.

European markets and Norwegian reservoirs

By combining price simulations from future marked scenarios with hydrodynamic modelling of a given reservoir, we have shown that it is possible to test how different operational regimes of the hydropower system can influence water level fluctuations, temperature, ice-cover and mixing of water.

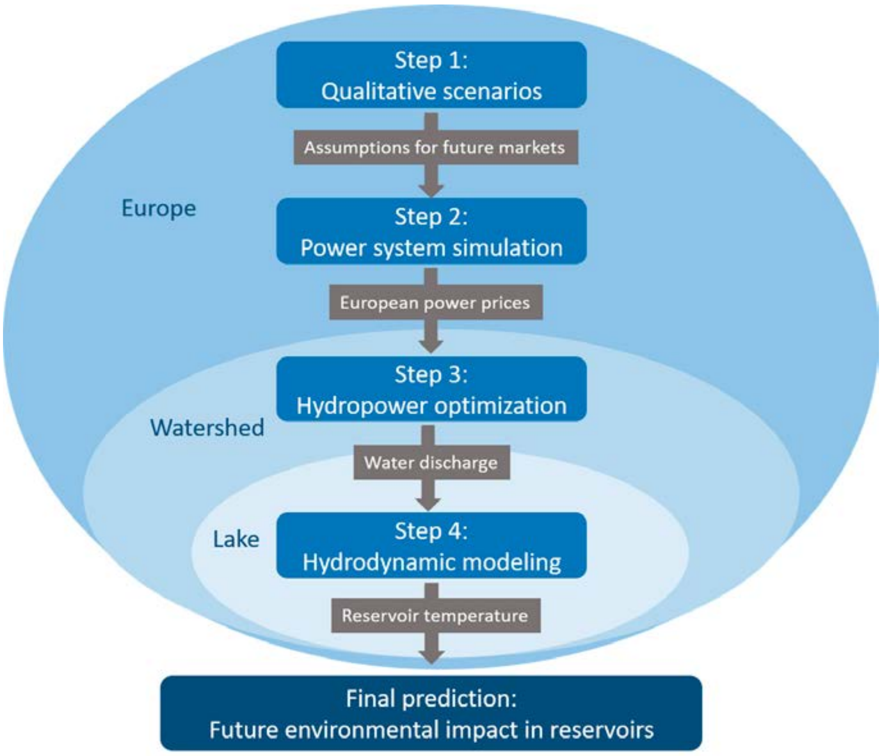
Our method has four steps, where output from one model is used as input to the next model. By connecting the models, we have linked all levels from qualitative scenarios for the European market, down to environmental impacts in a single reservoir.

The first step is the HydroBalance scenarios for large-scale balancing and storage from Norwegian hydropower in the year 2050. The assumptions from these scenarios are used in price simulations for the European marked, which is the second model. In the third step, these prices are then used in ProdRisk, a model used by Nordic hydropower producers to optimize and plan their power production. In the fourth model, the resulting water levels and discharge from these power production simulations is used as an input in the lake model CE-QUAL-W2 to identify changes in environmental conditions.

Promising method

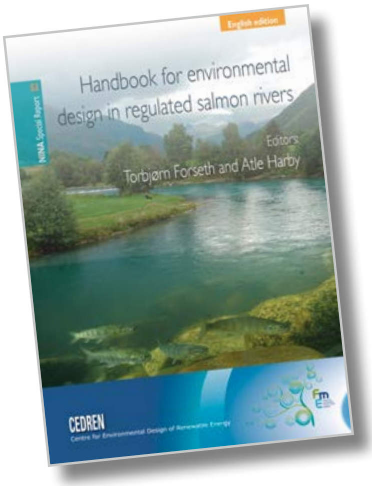
The method is tested in one reservoir only, but the findings indicate that this way of combining market simulations with reservoir modelling is promising for future work. However, to use this method, we need quite detailed data. We found that maps of reservoir depth and detailed reservoir temperature (temperature measured at different depths over all seasons) are missing for most Norwegian reservoirs. Today such data can be collected at low costs with the use of echosounding and temperature loggers, hence, we hope to rerun the model in more cases in the future.

By combining price simulations from future marked scenarios with hydrodynamic modelling of a given reservoir, we have shown that it is possible to test how different operational regimes of the hydropower system can influence water level fluctuations, temperature, ice-cover and mixing of water in hydropower reservoirs. Photo: Antti Eloranta



The figure illustrates the four steps in our method (blue boxes), where output from one model is used as input to the next model (grey boxes). By connecting the models, we have linked all levels from qualitative scenarios for the European market, down to environmental impacts in a single lake.

Environmental design in salmon rivers



The handbook for environmental design in regulated salmon rivers describes how to evaluate, develop and implement measures to improve conditions for salmon in regulated rivers, while simultaneously considering the important renewable energy production.

Transdisciplinary research within CEDREN allowed us to develop methods for combining the interest of salmon and hydropower production, with win-win solutions as the guiding vision. While power generation and regulation alters the physical characteristics of rivers and thus the environmental conditions under which salmon lives, the flip side is that regulation allows to implement environmental design solutions favorable to salmon. This idea was the foundation for the handbook.

From idea to system

The handbook has two major parts – a diagnostic part aimed at identifying bottlenecks for salmon production and restrictions and opportunities within the hydropower system, and a design solution part that describe habitat measures to address habitat bottlenecks and water flow related measures to address hydrological bottlenecks. Moreover, the book describes in detail how to collect the necessary data for salmon population and hydropower diagnostics and a suite of tools to find the best design solutions. Effects of different measures for the salmon population can be estimated a priori, and weighed against effects on hydropower production. Costly flow release regimes can sometimes be replaced with habitat improvements.

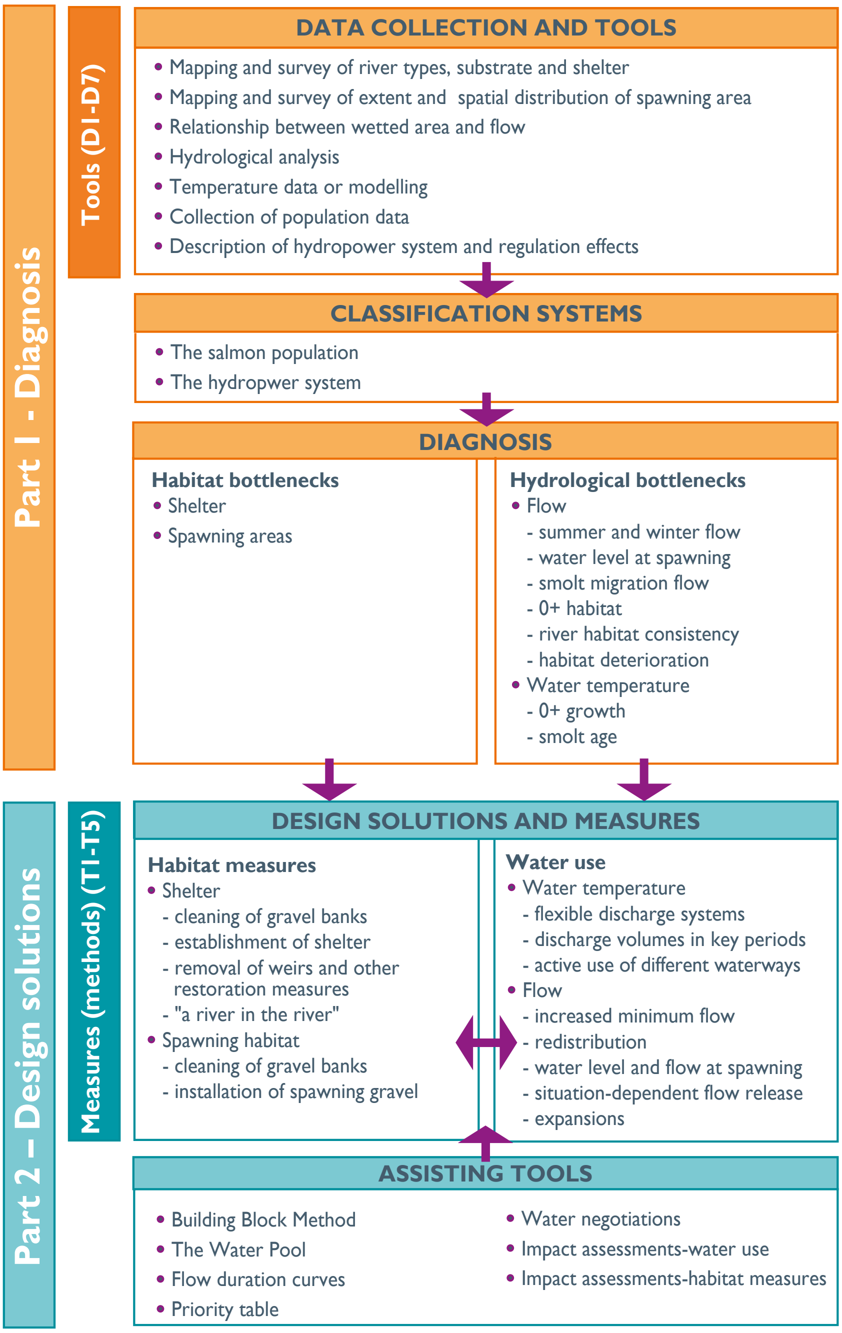
From system to impact

In parallel to the development of the environmental design system, it was applied in a river system in southern Norway. A solution was developed that combined expansion of the hydropower installations and increased energy production with doubling of the salmon production. This solution is now in the process of being implemented. Two other major and several smaller environmental design projects are ongoing or completed. The system has had a large impact on current management practices of energy and environmental agencies. Its impact is expected to grow, due to new environmental requirements through the EU Water Framework Directive, the Norwegian Biodiversity Act and the on-going revision of hydropower licenses.

From the original Norwegian version published in 2013, the handbook has extended its potential impact through an English version published in 2014 and a Chinese translation in 2016.

Photo: Helge Skoglund

Once a diagnosis has been established practical measures may be undertaken in accordance with detailed descriptions in the handbook. Here, a new spawning area is under construction. Photo: Ulrich Pulg.



Flowchart illustrating the major parts and ideas of the handbook, from data collection, via the diagnosis to design solutions and measures. A set of tools is also provided to help the user in a systematic way.

Fundamental salmonid research in CEDREN

To be able to produce important end products in CEDREN, such as the handbooks on environmental solutions in regulated rivers, the center depended on performing fundamental research on the population dynamics of salmonids.

Population dynamics

Population dynamics is the variation in population size (number of fish) in time and space, and the research focuses on exploring the reason for this variation. Density dependence is central, which is various mechanisms that cause growth and survival of fish to vary with the density of fish. The most common pattern is reduced growth or higher mortality at high fish densities due to competition for food or space. However, environmental conditions such as physical habitat, water temperature, ice conditions and water flow also influence the growth and survival of the fish. The relative importance of density dependence and the influence of environmental factors has been a central topic within biology for centuries.

Salmonid research in CEDREN

Through laboratory studies, experiments in nature-like stream channels, field studies, analyses of existing field data and the development of an individual based full life cycle model (IB-Salmon), we have explored the relative importance of density regulation and environmental factors for riverine salmonids. This has resulted in several papers in general ecology as well as fish ecology journals. We focused on filling important knowledge gaps, particularly related to the importance of water flow, but the research has contributed to the general understanding of population dynamics of salmonids and other animals. Also, the CEDREN-work on the earliest life stages of salmonids has extended our knowledge on this important part of their life in rivers. The PhD students and post docs were the drivers of this work in CEDREN.

What is it good for?

Merged with the large knowledge base on salmonid ecology, the fundamental studies in CEDREN allowed us to provide important answers to questions relevant for improving conditions for salmonids in regulated rivers. What is the population level effects of stranding and mortality during rapid down ramping of hydropower stations – in the short and long term? What is the optimal flow for juvenile salmonids in river sections with reduced flow due to hydropower? Why can addition of spawning gravel enhance juvenile production on one river section and have no effects in another? Is low temperature during larvae emergence from the gravel important for survival?

From fundamental research to solutions

The answers to these and several other questions was the foundation for developing the mapping methods, diagnostic systems and the design solutions in the "Environmental Design for Atlantic Salmon in Regulated Rivers" handbook, as well as for developing operational strategies for hydropower plants to reduce negative effects of hydropeaking in the book "Environmental Effects of Hydropeaking: Knowledge Status and Recommendation for Management and Industry". In CEDREN, the transition from fundamental research to applied recommendations and practices has been particularly effective.

Maxim Teichert used small artificial streams at Ims Research Station when he found that fish density and shelter availability was important for explaining increased growth with increased water flow.

Helge Skoglund performed studies in the field, artificial streams, stream channels and tanks when he refuted some old "truths" and showed that the flexibility of the salmonid alevins allow them to handle low spring temperatures.

Six stream channels in Paltamo, Finland was an important arena for Michael Puffer when he showed that daily peaking waterflow had only small effects on energy storage and growth of salmon parr.
Photo: Per Harald Olsen

Individual based modelling tool for Atlantic salmon

The Individual-based salmon (IB-Salmon) model can be used to explore impacts on Atlantic salmon populations of hydropower regulation, climate change and new mitigation measures.

Atlantic salmon populations have been in long term decline throughout their distribution range, partly due to natural fluctuations but also due to a number of anthropogenic factors. While the general knowledge on this species is extensive, a modelling tool to explore major impact factors was lacking. In CEDREN, the population model IB-salmon was developed to simulate the complete life-cycle of Atlantic salmon, from early life in the river until they migrate to the sea as smolts, and return as adults for spawning.

Individual based model

The model tracks individual fish and predicts growth, survival and movements within the river using deterministic and stochastic functions, parameterized using relationships established in the literature alongside empirical experiments conducted within CEDREN.

The model has been used in a variety of projects related to effects and potential mitigation of climate change on populations of Atlantic salmon in regulated rivers, hydropeaking and stranding and for evaluation alternative mitigation measures on production of Atlantic salmon in regulated rivers.

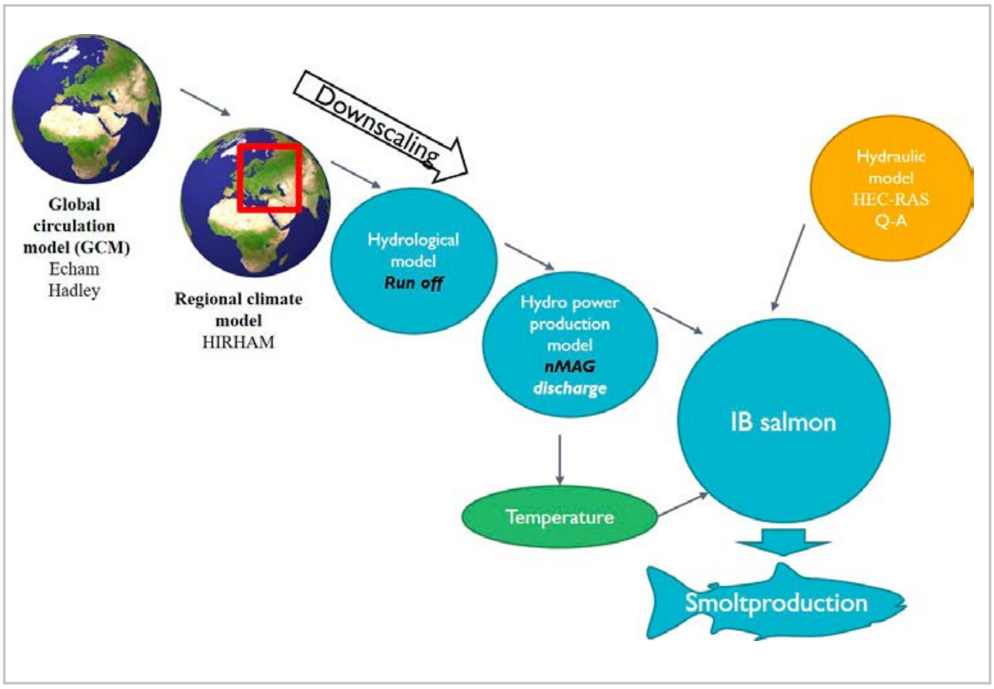
Effects of climate change

Climate change is expected to have strong effects on population abundance of salmon. We compared the effect of projected climate changes on salmon populations in southern, western and northern Norway. In the northern population, increased water temperatures cause faster growth and higher smolt production. In the western and southern population smolt production decreased in simulations of future climate conditions. Thus, climate change may be positive or negative depending on the location of the population. In a southern population, model simulations showed that negative effects of climate change could be mitigated by increasing environmental flow release during the critical summer periods.

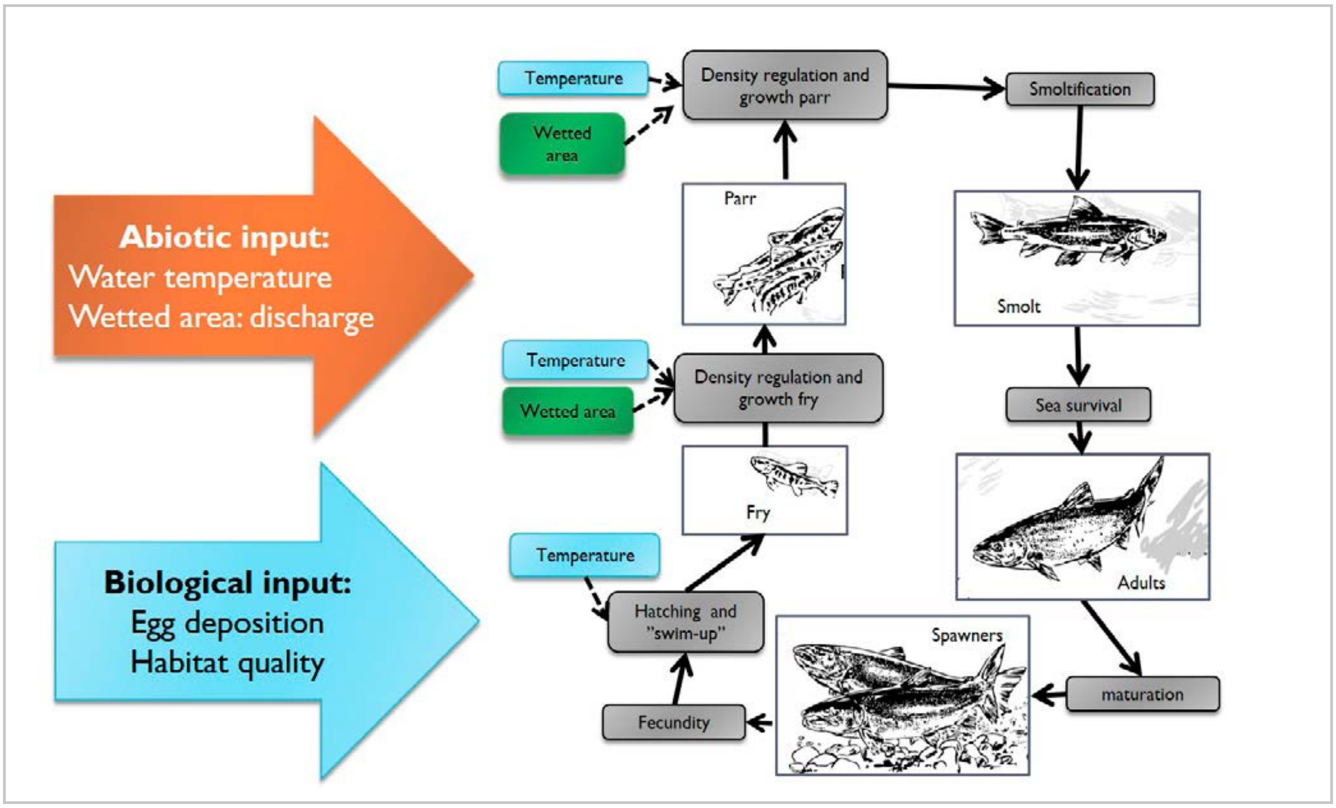
IB-Salmon in environmental design studies

The evaluation of alternative mitigation measures is important to optimize environmental flow regime in regulated rivers, in trade-offs between the production of salmon smolts and the production of hydropower. The IB-Salmon model has been used to compare mitigation measures in a bypassed reach of the river Mandalselva in southern Norway. Simulations showed that habitat measures had lower costs for similar gains in salmon production compared to different environmental flow scenarios.

Stranding of juvenile fish can be a major impact of hydropeaking operations in regulated rivers. Several experimental studies have explored the risk and extent of stranding, but effects on the population level are more challenging to estimate. In CEDREN, the IB-salmon model was parametrized for a river in vestern Norway. Simulations showed that stranding mortality of older parr had larger effects on the population than stranding of earlier life-stages.



Schematic view of how to downscale climate change scenarios from Global Circulation Models to local effects.



Schematic view of the most important features if the individual based model, IB salmon, designed to simulate the complete life cycle of Atlantic salmon and to predict population characteristics.

Improved fishways by simple reconstruction

More than 90 % of the fishways in Norwegian inland rivers are pool-and-weir or denil types where the fish have to jump from one level to another in order to pass the dam. Such fishways are constructed for salmon, but are still widely used in rivers and river sections without salmon.

The "salmon fishways" require high swimming capacity and are not optimal for species like grayling, trout and whitefish, which prefer to swim at the bottom of the river.

Redisigning fishways

Safepass are investigating if it is possible to reconstruct an existing pool-and-weir fishway to a modified "vertical-slot fishway" at the Høyegga dam in the river Glomma. Vertical-slot fishways are considered to be the best type of fishway in river systems with many different fish species, and gives fish a possibility to swim through at the bottom.

In 2016, we modified all the 22 pools in the classical "salmon fishway" at Høyegga in the Glomma river. This was done by sawing slots from the top to the bottom of the pools allowing the fish to swim through the holes instead of having to jump. The pool beds were then filled with gravel and rocks to simulate natural rivers.

Promising results

After the reconstruction, it was possible for the fish to swim from one pool to another instead of having to jump. Preliminary results show that the conditions in the fishway are improved for species like grayling, whitefish and trout (reduced water velocity and energy density).

The project is still running and the results will be evaluated in 2017 and 2018. However, video recordings show that more grayling and trout are passing through in the fishway than ever before, despite a short opening time in 2016. If the project proves to be successful, many other "salmon fishways" in the Glomma and other inland rivers can be reconstructed in the same way at a relatively low cost.

A fishway at Høyegga in the Glomma river has been transformed from a "salmon fishway" to a "vertical-slot fishway" by sawing slots from the top to the bottom of the pools allowing the fish to swim through the holes instead of having to jump. Photo: Jon Museth

Cost-efficient measures in regulated rivers

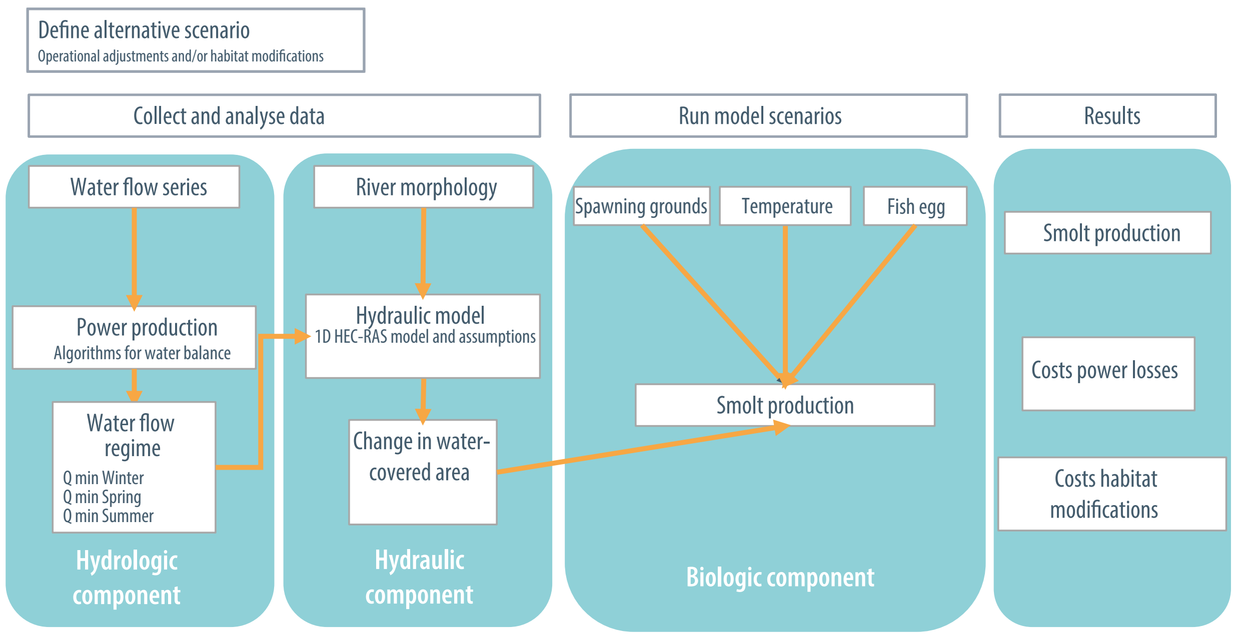
New tools can support finding the best combination of operational adjustments of the power production and habitat measures in regulated rivers.

Multi-criteria analysis have been developed and demonstrated for the purpose of finding the best solution where multiple user interests are taken into consideration. The method developed makes it possible to simulate the effects of various combinations of flow releases and habitat adjust¬ments on the ecosystem, recreational fishing, river aesthet¬ics and the power production, and make balanced decisions. The method can take into account a wide range of data and information, and present this is a consistent manner.

The method was demonstrated in the Mandal river, where a set of possible flow releases and habitat adjustments were simulated for the purpose of finding the optimum combination, with respect to all interests present in the river. A range of stakeholders followed the process and expressed their individual views on the importance of interests such as game fishing, landscape qualities and power production. This was fed into the multi-criteria tool and the tool revealed how the weight, or importance assign to the various interests, affected the outcome, and ultimately the choice of measures.

Selected conclusions from the Mandal river study:

- The new method makes it easier to discuss restoration alternatives across user interests
- The new method can be used to map what parts of the process which gives the most relevant decision-making information
- The new method can be used for cost-efficiency analysis given specific costs of habitat adjustments and loss of power production, also considering the potential for fish production increase.



Scematic view of components in the multi-criteria analysis system.

Environmental adapted hydropeaking

CEDREN scientists have developed a method of evaluating the impacts of hydropeaking and flexible operation of hydropower on fish in downstream rivers. The method takes into account the severity of hydro-peaking operations and the vulnerability of the fish population and river system, and provides the scientific basis for environmental adapted hydropeaking operations.

The need for power balancing power

With the growing share of intermittent renewable energy sources, such as solar and wind power, we can expect that hydropower reservoirs will play an increasingly important role in balancing generation and load. Hydropeaking operations from hydropower plants with outlet in rivers will lead to rapid and frequent changes in discharge and water level in downstream rivers.

After studying environmental impacts of hydropeaking in rivers, CEDREN developed a method for determining the ecological effects in downstream rivers. This method describes a systematic approach to assess the vulnerability of a river and the physical characteristics of hydropeaking operations, which combined gives the the total impact.

Assessment of vulnerability

A series of indicators that focus on salmonids are used to assess the vulnerability of a given river reach including the average number of female fish and the total area and distribution of spawning grounds. The evaluation is based on the methodology used in CEDREN's 'Handbook for Environmental Design in Regulated Salmon Rivers'.

The evaluation also takes into account the effects of river regulation and other impacts than hydropeaking itself. These include acidification, pollution, diseases and parasites, as these effects add to the vulnerability of the fish population in the river.

In order to assess the impact of hydropeaking, we must grade the rate of change in water level, the extent of the dewatered area, the magnitude of flow changes and when and how often the changes occur. This permits an overall assessment of the effects.

Environmental adapted hydropeaking

Use of the system will form a basis for identifying the best possible measures to reduce the environmental impacts from hydropeaking operations. It will also provide a platform for balancing the need for short-term regulation of power production, and at the same time sustaining ecosystems in rivers exposed to such types of operations.

Hydropeaking operations can be characterised as introducing more rapid and frequent changes in discharge and water level than naturally occurring in unregulated rivers or in rivers exposed to traditional, base-load production. Hydropeaking operations can pose a risk to human beings and the ecosystem. Photo: Tor Haakon Bakken

The book summarises state-of-the art about environmental impacts from hydropeaking operations in rivers.

CEDREN has developed a system to acsess hydropeaking, in order to find environmental adapted operations. The classification system is a tool and guidance to the hydropower industry and the authorities. Photo: Håkon Sundt

Water consumption by hydropower

Water consumption represents a reputational risk to the power producer as hydropower can be viewed as a large water consumer. In complex river basin with competing water use and several reservoirs, water consumption can also pose a financial risk to the power producer.

Need for improved methodology

There is a growing interest and concern related to assessment of water consumption from products and services, including hydropower production. Water consumption from hydropower production relates primarily to evaporation from reservoir surfaces. Reservoirs may provide several water-related services in addition to energy production, and can regulate the water flow to a cascade of hydropower plants. The methodology to calculate water consumption from hydropower production clearly needed improvements. CEDREN has contributed significantly to an improved methodology, which includes the preparation of the scientific basis for using the net effect of reservoirs and the hydropower production on the local water resources, in contrast to gross calculations that dominated until recently.

Water consumption from Norwegian hydropower projects

Research in CEDREN has revealed that the net water consumption from Norwegian hydropower is very low compared to hydropower projects in warmer regions, as well as when compared to other technologies. As several reservoirs are developed on existing lakes, the gross water losses can be comparable to lower-range numbers in international studies. The studies in Norway has also illustrated the importance of defining a better methodology to allocate the water losses between differenthydropower plants within of the same river basin or regulation system.

Based on studies in semi-arid regions it is clear that the availability of water resources for hydropower production can be very sensitive to climate change and irrigation withdrawals. Upstream regulations might represent a risk to downstream power production, due to withdrawals of water and evaporative losses from reservoir surfaces. In highly complex basins there are close inter-dependencies between water users, but reservoirs can create mutual benefits.

Impact of the research on policies

Important international bodies have adopted several of the findings in CEDREN. The World Energy Council (WEC) has pointed out that the net approach is the preferred way of calculating water consumption, and The International Energy Agency (IEA) underline the complexity of reservoirs and excludes hydropower from comparison with other technologies. The ISO Water Footprint standard acknowledges the role of reservoirs in increasing the water availability in dry periods.

The multipurpose reservoir Lake Mead on Colorado River just upstream of Hoover Dam and Power Plant. The photo is from 2015, close to the end of the 4 years' drought.
Photo: Tor Haakon Bakken

Colorado River a few kms downstream of Hoover Dam and Lake Mead.
Photo: Tor Haakon Bakken

Nyamba ya Mungu Reservoir in Pangani River, close to Moshi, Tanzania.
Photo: Tor Haakon Bakken

Are conflicts over powerlines avoidable?

Conflicts often arise when new power lines are planned and constructed. Studies carried out by CEDREN show, that disagreements can be avoided or significantly reduced. We examined the underlying components of conflicts. Legitimacy issues arise because it is difficult to communicate power system-oriented decisions. In addition, many players do not get involved until the decisions are made, which is when they can appeal. This adds time and cost to grid development.

Expert-driven development in Norway

Studies of historical guidelines and management procedures show that the grid development regime in Norway is expert-driven and dominated by electric power engineers. In the UK on the other hand, national policy has a bigger say in these matters, while in Sweden, regional and local authorities are much more closely involved. This was evident in the 2010 conflict over the path selected for the powerline (Sima-to-Samnanger) along the Hardanger fjord in Western Norway. Key community players had more to gain from protesting through informal channels such as massmedia than from participating in the formal processes even though they had the opportunity to be heard.

Public knowledge

Case studies of a number of development projects of the national grids in Norway and the UK show that while professionals in this field in general are positive to the planning process, local people tend to be far more negative, and regard participation in planning processes as being challenging and not very realistic. The Norwegian public in general is positively inclined towards grid expansion, but the average inhabitant has little knowledge about the grid and the players involved.

Political coordination of public interests

It appears that the need for security of supply is more significant in dictating grid development decisions than any political platform or support. Compensation for local communities like investments that benefit the local community or the local environment are preferable to direct financial compensation. Better coordination of different societal interests would offer benefits. The consequence could be fewer conflicts and a reduction in the overall use of time and resources.

Recommendation

To strengthen the social acceptance at large CEDREN, research provides the following recommendations:

- Plan communication as a foundation for open dialogue
- Be clear on why the project is promoted
- Avoid logical inconsistencies
- Provide complete information
- Acknowledge scientific uncertainty
- Identify acceptable forms of compensation
- Remain committed to dialogue throughout the life-cycle of the project

Conflicts often arise when new power lines are planned and constructed. Studies carried out by CEDREN show that disagreements can be avoided or significantly reduced. Photo: Statnett

The photo shows people demonstrating against a new power line crossing the scenic Hardanger fjord.
Photo: © Helge Sunde/ SAMFOTO

The challenge of managing different political concerns

Regional plans for all water regions in Norway have been approved by the government, but there remains uncertainties related to how environmental objectives actually are going to be achieved in rivers impacted by hydropower production.

The European Union's Renewable Energy Sources Directive (RES) which requires Norway to generate 67.5% of its electricity from renewable sources by 2020, stimulates the introduction of new policy instruments. The joint Norwegian-Swedish Renewable Electricity Certificate market introduced in 2012 to stimulate renewable electricity production, is a direct result of the RES Directive commitments. The Water Framework Directive (WFD) requires Norway to improve the environmental quality of and within rivers – including waterways impacted by hydropower production.

A double environmental challenge

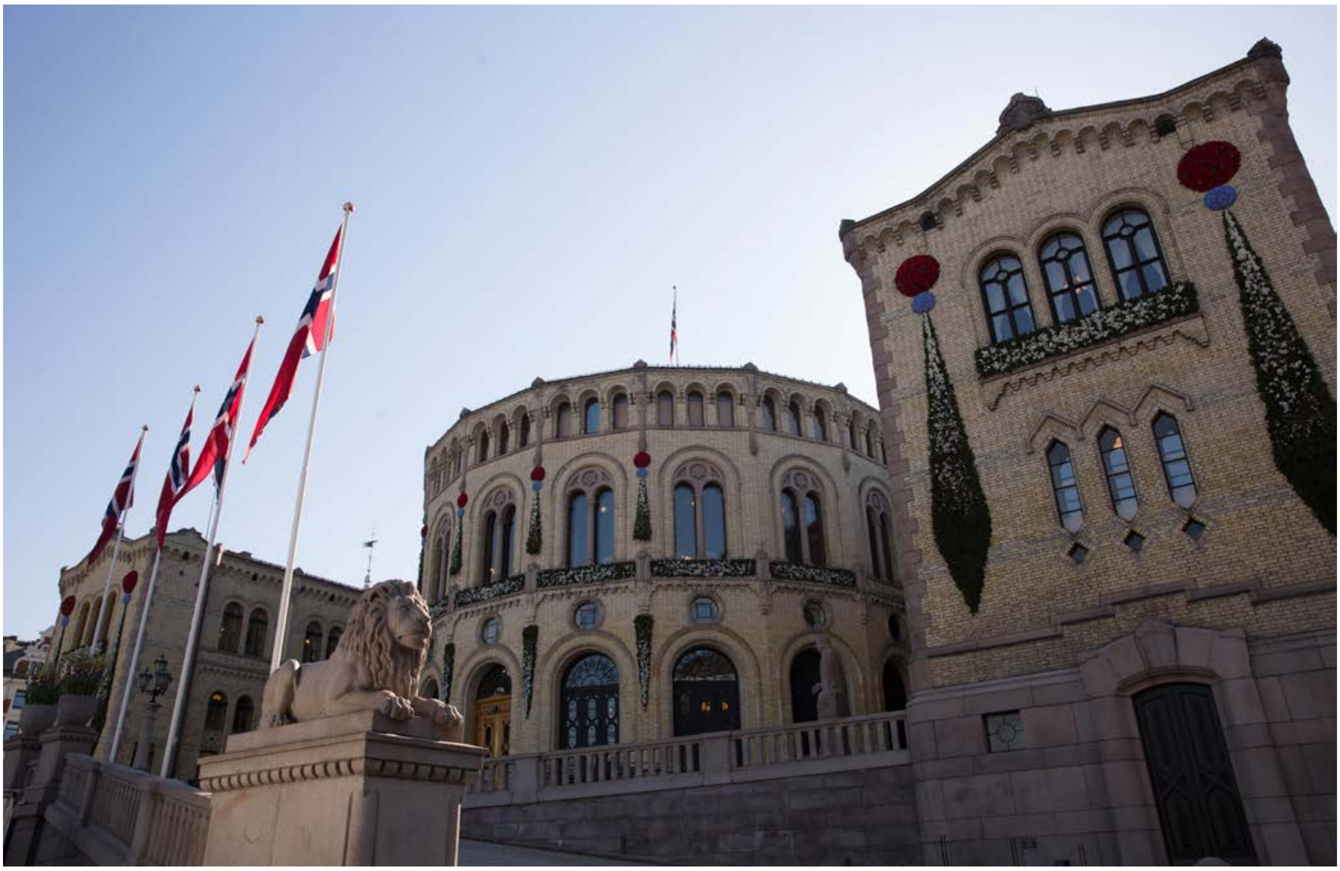
Energy and environmental policy initiatives often appear to be part of a zero-sum game in which one is obliged to choose between energy production and conservation of the environment. The promotion of renewable electricity will contribute to clean and climate friendly energy supplyes, but these environmental references are not always tuned towards other environmental impacts that hydropower production is causing. A double environmental challenge is prevailing by potentially colliding political forces and still there is not very clear how these concerns are reconciled. However, CEDREN research shows that there are nuances to such a conclusion. It is possible to maintain energy production while improving environmental qualities, but a prerequisite is to remain open minded. One example is the case of small hydropower plants.

Small is not always beautiful

Small hydropower projects below 10 MW installed capacity have been preferred politically in Norway, but all energy projects have an impact on the environment. If we regard them in terms of kilowatt-hours generated, small hydropower plants are less environmentally friendly compared too large hydropower projects. Still small hydropower plants are the priority among core stakeholders and this is done despite the increasing acknowledgement of the need for balancing services – a provision that only larger hydropower plants with storage can supply.

A need for reconciling energy and environmental concerns

CEDREN documents that political or public priorities tend to have a decisive influence on the preferred strategy for energy and in particular hydropower development. Environmental design in regulated rivers can give more sustainable hydropower solutions, but lack of policy coordination across sectoral interest and between different levels of decision making, causes less optimal solutions.



Research conducted by CEDREN has confirmed a need for more coordinated political steering across sectoral interests and levels of decision-making. Photo: Morten Brakestad, Stortinget

CEDREN has documented that there are uncertainties related to how environmental objectives can be achieved in rivers impacted by hydropower production. Photo: Hans-Petter Fjeldstad

10 International cooperation

CEDREN has had a strong focus on international acitivities. The following objectives are included in the CEDREN strategic platform:

1. CEDREN will utilise the expertise and knowledge of the international R&D community to further develop the centre and apply this to the mutual benefit of CEDREN's R&D partners and user partners as well as international research groups.
2. CEDREN will secure its own access to the most up-to-date expertise and technology in the area of renewable energy development.
3. CEDREN will promote the development of sustainable, renewable energy solutions at the international level.
4. CEDREN will transfer expertise developed in Norway to other R&D groups and to other parts of the world.
5. CEDREN will seek to open up new international markets for Norwegian R&D players, consultants and other industry players.

The centre effect

CEDREN has been very visible internationally and the concept of thematic research centres has been highly appreciated and recognized as an excellent platform to increase international collaboration. In all projects, CEDREN has collaborated with internationally recognised research groups. Our experience is that it is easier to find and attract the best research partners when the research activities are carried out under the umbrella of a research centre. Similarly, it has been easy to get access to workshops, seminars and meetings with internationally recognized experts when the scientists and students can show they are a part of a large thematic research centre like CEDREN.

CEDREN has participated in numerous conferences and meetings promoting environmental design of renewable energy worldwide, and has even organized specific seminars and workshops in China, Ethiopia, France, Germany, India, Netherlands, Romania, Tanzania, Turkey, Uganda, USA and UK. CEDREN scientists have also been engaged in international organisations to deliver knowledge and reports to the public through the Intergovernmental Panel on Climate Change (IPCC), International Energy Agency (IEA), International Hydropower Association (IHA), European Energy Research Alliance (EERA), and the Bern convention.

Environmental design

Some of the methods and models developed in CEDREN, have been tested and used abroad in Albania, Australia, Austria, Canada, China, Ethiopia, Finland, France, Georgia, Germany, India, Latvia, Malaysia, Netherlands, New Zealand, Portugal, Romania, Spain, Sweden, Switzerland, Turkey and UK, under different climatic and natural conditions. Currently, CEDREN scientists are partners in on-going research projects funded by the European Union, taking methods and models for environmental design of renewable energy to Europe.

Organising international conferences in Norway

During the lifetime of CEDREN, involved scientists and partners have organised several large

CEDREN has cooperated closely with Chinese scientists on environmentally friendly hydropower development. The photo shows a Chinese hydropower owner explaining about a new dam and refurbished hydropower plant. CEDREN scientists gave advice to the project. Photo: Peggy Zinke

Collaboration with the EU. In 2015, CEDREN co-organised a seminar in Istanbul with the European Commission Joint Research Centre, inviting participants from the Balkans and Turkey. Photo: Ånund Killingtveit

The workshop Sustainable Hydropower Reservoirs - Challenges and opportunities was held in Adis Abeba, Ethiopia in 2014. Photo: Ånund Killingtveit international research conferences in Norway. In May 2011, the international Conference on Wind Energy and Wildlife Impacts was organised in Trondheim, and in June 2014, CEDREN researchers organised the 10th International Symposium on Ecohydraulics in Trondheim. The Renewable Energy Research Conference (RERC) was held in Trondheim in 2010 and 2012 and in Oslo in 2014. The conferences all had attracted about 300-400 participants from more than 30 different countries.

Attracting international partners

In the start-up, CEDREN had no international user partners. Later, user partners like E.ON and ENBW from Germany and EDF from France have engaged in different CEDREN projects. CEDREN has also had information exchange, dialogue and discussions with energy companies, authorities and NGOs worldwide.

Increased interest in Norwegian hydropower

Many countries are increasing their share of wind and solar energy in their electricity mix, leading to increased need for balancing power and storing energy. Ambitious targets for wind and solar energy development in continental Europe and UK are leading to an interest in Norwegian hydropower for potential storage and balancing services. CEDREN has conducted research in this topic for many years, and we have had extensive information exchange, discussions and interactions with European industry, researchers, authorities, stakeholders and media. CEDRENs research activities in this field, has also lead to closer collaboration with the EU Commission and their Joint Research Centre.

The nature of Canada

The nature in Canada is comparable to Norway, thus giving similar opportunities and challenges related to hydropower. For that reason, CEDREN established a collaboration with the Canadian research network "HydroNet". Scientists and students from both countries have visited each other, resulting in joint research projects and common scientific publications.

Everything is big in China

China is the world's largest producer of hydropower, wind power and solar power. CEDREN established collaboration with several Chinese universities and research institutes to exchange knowledge and work together for sustainable hydropower and the use of hydropower to better integrate other renewables. Meetings, workshops, seminars and courses have been organised both in China and Norway, and both teams have learned much from each other. The "Handbook for environmental design of regulated salmon rivers" has even been translated into Chinese.

Photo: Eline Hegvik

11 Training of researchers

The education of PhD and Post Doc candidates and Master students has been one of the main tasks in CEDREN.

PhD-program

The most important contribution here is the PhD program. In CEDREN, a very significant share of the total allocation of funds was on PhD research, infrastructure and instrumentation for PhD research.

In total, 19 PhDs have finished, 15 of these fully financed by CEDREN and 4 financed from other sources but working on topics closely connected to CEDREN. In addition, five more PhDs are working in projects started in the last 2-3 years, three of these will finish in 2017 and the last two in 2018, bringing the expected total number of PhDs up to 24.

PhDs candidates receive their research training by a combination of coursework, individual research under guidance of one or more supervisors, and dissemination of results in papers and a final thesis. In addition, most PhDs at NTNU will be involved in other relevant duties as for other university researchers:

- Contribute to teaching
- Laboratory and practice teaching
- Supervision and exam work within their areas of expertise
- Provide training in the use and operation of research infrastructure
- Participating in dissemination, exhibitions and collection activities
- Work associated with research administration in connection with organization of academic conferences or assistance in the preparation of applications for research projects
- Courses in university teaching, training in health, safety and the environment (HSE), and similar, which are regarded as necessary for carrying out the required duties

The relationship between the PhD-candidate and the supervisors is an important part of any doctoral project. The main supervisor plays a significant role as academic contact, expert, supporter and project manager. At NTNU there is a general rule that all PhD-candidates should have at least two supervisors. It is important that the responsibilities are clearly defined among the supervisors. The main supervisor has a specific responsibility for coordinating the supervision. Many of the CEDREN researchers have been involved as supervisors for PhDs.

PhD recruitment

PhD education and recruitment of researchers are among NTNU's most important tasks, and the task of strengthening the quality and relevance of our education is highly prioritized. All PhD and Post Doc positions in CEDREN have been announced in external media and on the "Job Norge" portal. Also, international research networks were used frequently in order to spread information and try to recruit the best candidates. Generally, there were a majority of international applicant, many of these with MSc from the Hydropower Development Program (HPD).

The balance between Norwegian and International PhD and Post Docs (47% Norwegian) is good, also the gender balance (41% Female). The majority (87%) of PhD candidates graduated at NTNU, the rest at University of Bergen and University of Exeter, UK.

PhD candidate Hans-Petter Fjeldstad and MSc student from Pakistan at field-work in Dalåa. Photo: Ånund Killingtveit

PhD and PostDoc interaction

Researchers in CEDREN, including PhD and PostDoc candidates, have had very different backgrounds and have worked within a wide range of scientific topics: biology, social sciences and engineering; fish ladders, tunnels and power lines; hydropower and wind power, all within the topic of renewable energy and connected in not so obvious ways. This multi-diciplinary approach have been the main strength in CEDREN research but also poses some difficulties, as it may sometimes be difficult to see how different research topics fit together. In order to create a "CEDREN-family" for the researchers and in particular PhD and PostDoc candidates, regular meetings and excursions has been important. We have arranged annual "PhD-tours" to interesting sites with wind- and hydropower plants, visited field experiment sites in rivers, studied power lines and landscape impacts and discussed the balance between technical requirements, impacts and how to be "respecting nature". At every tour, PhDs and researchers working at the site can explain and inform each other about their work. We also have invited and visited many CEDREN-partners during these visits, for example at Statkraft's wind power site at Smøla, Sira-Kvina power company at Tonstad, TrønderEnergi in Orkla river and Lyse Kraft at multiple sites near Stavanger.

Master students

In CEDREN, the participation of MSc students have been very important for the research activities. A typical scenario in many of the projects is to have one or more PhD or PostDocs, each of these can have 2-4 MSc students who do their thesis by running lab- or fieldwork projects, testing and verifying models and methods, and the first testing of new concepts. Such cooperation is very useful both for the PhD candidate and other researchers, and for the MSc students. This has often proved to be one of the best methods for bringing new methodology out into the industry.

It total, more than 100 MSc students have contributed to CEDREN projects in their thesis work. In addition, many were employed in summer job activities, and as assistants in lab and fieldwork. This has also been a successful way to recruit new international PhD students, especially among European students.

Dissemination of CEDREN results in MSc courses at NTNU

The concept of research-based teaching is important for all MSc programs, and with professors at NTNU strongly involved in the research activities at CEDREN, it was easy to bring new research results into the curriculum for MSc students. There are many such examples, here we can only mention a few topics where results have been included in courses at NTNU:

- Integration of Norwegian hydropower system in the European power-system
- Climate change impacts on water resources and hydropower
- Environmental design of hydropower
- Pumped storage hydropower development

Teaching in lectures can contribute to awareness and interest in the topic, leading in the next turn to a MSc thesis and for some, to a PhD project. Reporting from an active ongoing research project is a very effective way to create interest among students, and with the long time-horizon of a FME it is also possible to let some students proceed to MSc and PhD work before the project has been closed. This is a unique advantage for the FME concept, and has been very important in CEDREN.

The Athens program

In 2014 NTNU decided to develop a one-week course on the topic "Sustainable hydropower" for students in the European ATHENS program. The objective was to give students an introduction to hydropower technology and show the wide area of expertise that is needed for planning, construction and operation of modern hydropower plants, and the importance of using "Environmental design" methodology. The ATHENS program is a network formed by 14 European universities from equally many countries, where students are offered to participate in specialized courses in topics not covered at their own home university. Each course typically takes one week.

The course proved to be very popular, about 25 students from 10 countries were admitted and came to Trondheim and NTNU in March 2014. In the following years, the course has been repeated nearly every year, always with a high number of applicants.

Many topics from CEDREN research are presented, not only in lectures but also including site visits to hydropower plants, laboratories and field research stations near Trondheim. The course includes an exam which gives 3 ECTS when passing so that students can have it accepted as part of their curriculum.

Course development

Research results from CEDREN have been incorporated in several existing courses at NTNU, for example TVM5135 Hydropower planning, TVM5132 Prefeasibility study of hydropower projects and TVM4101 Vann og miljøteknikk.

The course TVM5172 Water resources management have been completely redesigned in order to introduce "Environmental design" principles from CEDREN and also "Sustainability assessment" methodology as developed by IHA.

Starting from 2017, a new EVU course (EVU = Continuing Education at NTNU) on «Environmental design of hydropower» will be introduced with start in September and October. This course will utilize handbooks and reports from CEDREN and many CEDREN researchers will be contributing as teachers. Professor Knut Alfredsen at Department of Civil and Environmental Engineering, NTNU is in charge, the course gives 7.5 ECTS if exam is passed.

ATHENS students in 2015 at Øvre Leirfoss. Photo Ånund Killingtveit

Employment of PhD-candidates

After having successfully defended their PhD thesis the CEDREN PhD-candidates were employed by the following type of organisations:

Employment of PhD-candidates (number)						
By centre company	By other companies	By public organisations	By university	By research institute	Outside Norway	**Total**
5	3	2	1	3	5	**19**

A new generation of environmental designers

The future of environmental design of renewable energy looks bright. By 2018, 24 PhD candidates will have completed their degrees and 7 Post Docs have finished their research projects.

I decided to do my PhD in CEDREN because it gave me the opportunity to do research on reversible pump-turbines, which is a highly relevant topic. The title of my PhD thesis is "Dynamic behavior of reversible pump-turbines in turbine mode of operation".

In my opinion, the advantage of being a CEDREN PhD candidate was that it gave me the opportunity to meet fellow student and professors working within a wide range of fields.

My best CEDREN memory is when I visited the Nant de Drance pumped storage plant in Switzerland during construction together with other master students, PhD studens, Post docs and professors in CEDREN.

Eve Cathrin Walseth
Senior advisor

Energi Norge AS

The operational flexibility and energy storage facilities put hydropower in a strategic position. However, hydropower operation in the winter can be challenging due to river ice. As a PhD candidate in CEDREN, I studied the ice conditions in a regulated river in the current and future climate. The title of my PhD thesis is "Theoretical journey to real world application".

In my opinion, the advantage of doing my work in CEDREN was that it gave me the opportunity to exchange ideas with an inter-disciplinary group of researchers. In addition, the day-to-day interaction in an international environment encouraged me to push further.

My best CEDREN memory is when I communicated my findings to the hydropower industry, stakeholders and private sector and thereby contributed to the transfer of knowledge from CEDREN to the user partners and society at large.

Netra Timalsina
Chartered dam safety engineer

Hydro Energi AS

Through CEDREN, I got access to the research facilities of the partners, such as the NINA research station at Ims, where I performed most of my experiments. CEDREN gave me the possibility to work with the leading researchers in my field from other institutions. As far as I know, I would not have had this opportunity in a regular PhD program. The various CEDREN meetings and seminars provided an arena for meeting with other researchers as well as people from the industry and public authorities.

The interdisciplinary profile of CEDREN gave me the opportunity to put my own work in a wider context beyond the significance of my own research project.

My best CEDREN memory is when I preformed field experiments at the NINA research station at Ims. During this time, I enjoyed the practical work as well as having time to reflect about the scientific questions that drove me.

Helge Skoglund
Senior researcher

Uni Research

12 Communication and dissemination

Communication and dissemination have been a central part of CEDREN, reflecting the commitment to deliver knowledge, innovations, solutions and new opportunities for renewable and sustainable energy production. Targeting academia and the scientific community, industry, authorities, stakeholders and the wider public, different measures were adapted to facilitate goals and objectives in communication, dissemination and knowledge exchange.

cedren.no in Norwegian and in English has been the main communication channel for day-to-day news about work, results and events. The website newsletter has about 420 users. In addition, CEDREN has used Facebook and Twitter actively.

Dialogue

CEDREN has had close personal dialogue with its partners, the scientific community and interest groups nationally and internationally. CEDREN has met with individual user partners 56 times, and the authorities 18 times throughout the project-period. Open dialogue has been important in order to meet expectations from user partners and to provide relevant research. All annual CEDREN seminars have been open to the public, and CEDREN has hosted numerous meetings, workshops and seminars on specific topics to enhance knowledge exchange and dialogue.

Publications

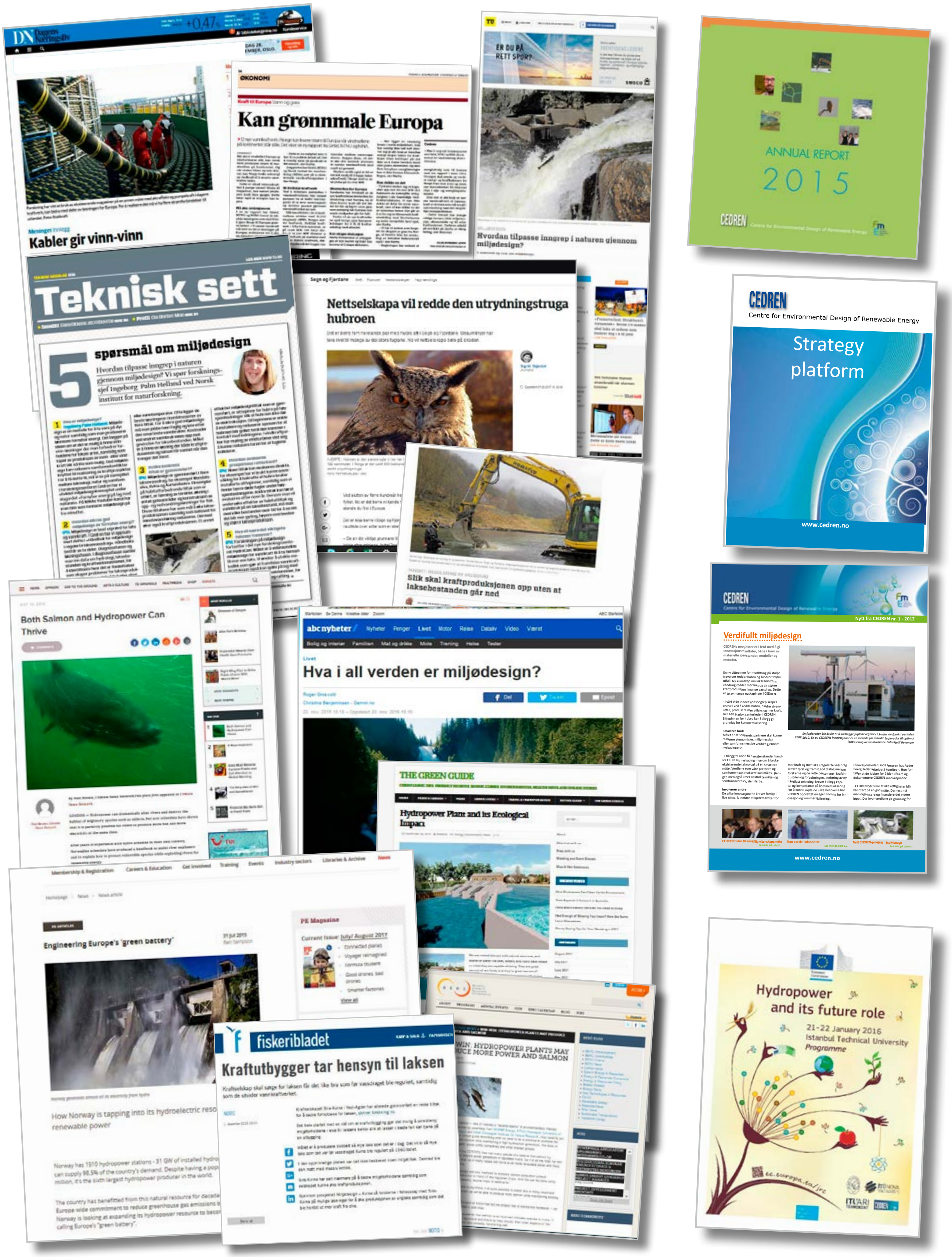
Scientific publications in peer-reviewed journals and presentations at conferences have been the major channel to disseminate research results to fellow researchers, resulting in about 170 scientific publications and more than 500 conference presentations.

In addition to scientific papers, CEDREN has communicated results as reports, briefs, memos, books, handbooks and booklets in order to reach target groups outside the scientific community. The "Handbook for environmental design in regulated salmon rivers" gives direct advice for users, and is translated to English and Chinese. The handbook is from 2017 the basis for a special course in "Environmental design in regulated rivers", given at NTNU. CEDREN has also produced a short film to introduce the concept of environmental design.

CEDREN has published five textbooks summarizing and illustrating results from research on hydropeaking effects, power lines and wildlife, wind power and challenges for birds, bats and reindeer, societal acceptance of renewable energy and opportunities and challenges for integration of Norwegian hydropower with European wind and solar power. A booklet presents 32 innovations from CEDREN. The user partners have characterized these as useful and highly relevant.

Media

One of the pillars in CEDREN's strategy is bringing relevant knowledge to the wider public. Managers, scientists and students in CEDREN have been encouraged to participate actively in media channels, ranging from both national and international newspapers, TV and radio, to special magazines, international web-based news and local press. There has been an increasing interest in CEDREN’s topics of research during the last eight years, and CEDREN results and knowledge have been exposed in the media in more than 1 000 articles.


DN Dagens Næringsliv
Kabler gir vinn-vinn
ØKONOMI
Kan grønnmale Europa
ER DU PÅ RETT SPOR?
Hvordan tilpasse inngrep i naturen gjennom miljødesign?
ANNUAL REPORT
2015
CEDREN
Teknisk sett
5 spørsmål om miljødesign
Nettselskapa vil redde den utrydningstruga hubroen
CEDREN
Centre for Environmental Design of Renewable Energy
Strategy platform
www.cedren.no
Slik skal kraftproduksjonen opp uten at laksebestanden går ned
Both Salmon and Hydropower Can Thrive
abc nyheter
Hva i all verden er miljødesign?
Verdifullt miljødesign
www.cedren.no
THE GREEN GUIDE
Hydropower Plant and its Ecological Impact
Engineering Europe's 'green battery'
PE Magazine
How Norway is tapping into its hydroelectric resources for renewable power
fiskeribladet
Kraftutbygger tar hensyn til laksen
Hydropower and its future role
21-22 January 2016
Istanbul Technical University
Programme

13 Effects of the centre for FME objectives

The research in CEDREN is closely linked to the ambitious targets in Norwegian and European energy, climate and environmental policy. CEDREN has developed new and innovative solutions for hydropower technology to meet future demands for more flexible operation and increased need for balancing and storage in the electricity system. This is important for the future energy system where much more un-regulated power from wind and solar sources will be integrated. At the same time, CEDREN has developed methods, models and guidelines to assess environmental impacts and find win-win solutions for hydropower production and the ecosystem.

To meet future demands for a secure and robust energy system, we need new and upgraded power transmission lines. CEDREN has developed methods and ready-to-use tools to find the most optimal routing of power transmission lines taking technical, economic, environmental and societal factors into considerations. This concept can also be used for siting of other types of infrastructure.

Wind power plants in an area used by birds, bats and other wildlife may cause conflicts and impacts on their population. Through new tools and methods developed in CEDREN, siting and operation of wind power plants can be better adapted to the environment, avoiding conflicts between wildlife and energy production.

Most of the methods, tools and results from CEDREN are important nationally as well as internationally, and may contribute to help other countries in developing renewable energy in a sustainable way. As CEDREN has had a strong focus on international knowledge exchange, we believe that the international community also will benefit from our results.

Finally, CEDREN has contributed to recruit many students at MSc and PhD levels, by highlighting challenging and interesting problems and topics in the renewable energy system.

Foto: Jan Djenner, Samfoto

14 Effects of CEDREN

Research partners and users from industryand authorities give their view on the effects of CEDREN.

SINTEF Energy Research

Knut Samdal
Research Director

SINTEF Energy Research

SINTEF has extensive research expertise in the field of hydropower, energy systems and power transmisson, which are key areas of focus in CEDREN. The coordination of a major international research centre such as CEDREN has been crucial to our research strategy and activity. SINTEF's vision is "Technology for a better society", and the environmental design of hydropower systems supplies research and technology that help us to achieve our vision.

Hydropower is the backbone of the Norwegian power system. SINTEF Energy Research has conducted research into hydropower for more than 60 years, involving projects linked to the improvement of grid operation and system services, and the optimal distribution of hydropower. At the CEDREN centre, SINTEF, NTNU and NINA have, in partnership with the industry, applied environmental design to elevate hydropower into the present day under the banner: "Renewable energy respecting nature." CEDREN has been a unique centre for multidisciplinary collaboration between research and technical groups from different backgrounds, as well as industrial concerns and the public sector.

Our collaboration with NINA and NTNU at the CEDREN centre has resulted in innovative cooperative clusters and many new spin-off projects. CEDREN has resulted in closer collaboration between the institutes, and will live on in the form of its spin-offs.

It has also led to closer collaboration with the industry in the field of environmental design. By attracting worldwide attention, research from the centre has helped hydropower and the industry to achieve an entirely new competitive status.

The coordination of a major and long-term research effort such as the CEDREN FME means that SINTEF has become a more attractive employer due to greater visibility and a boosted reputation. In this way, CEDREN, together with our other FME centres, has had an important role in the recruitment of new talent.

NINA

Norunn S. Myklebust
Managing Director

NINA

Being one of the research partners of CEDREN has given NINA the opportunity to realize our motto which is "Cooperation and expertise for a sustainable future".

NINA has a long history of research on environmentally friendly hydropower and wind power production, and are focusing on both environmental and societal concerns. The long-term predictability that the framework of a FME research centre provides, has given NINA the possibility for long-term strategic building of our energy research, amongst aquatic biologist, terrestrial biologists and social scientists.

In addition to playing an important role in the recruitment of scientific staff, with several CEDREN related PhDs and post docs, having the responsibility for communication in CEDREN has provided opportunity for growth and development of our communication department.

CEDREN has increased the possibility of winning more and larger research projects from the Research Council of Norway. This has strengthened our ability to improve the methodology used for assessing environmental impacts of power production. It has also given us the opportunity to invest in research infrastructure like a radar system developed especially for monitoring birds and advanced telemetry equipment for monitoring fish.

CEDREN has been crucial for a fruitful and interdisciplinary cooperation between the research partners, and has nurtured an international scientific network of researchers with an excellent knowhow of environmentally friendly energy production. The research centre has provided an important arena where researchers and user partners have been able to cooperate towards a common goal to develop good environmental solutions for the energy sector. Through CEDREN, NINA has gotten the opportunity to cooperate closely with hydrologists, hydropower engineers, industry and management to develop solutions to simultaneously increase ecological status, societal acceptance and power production. The FME program has opened doors to important arenas where NINA has been able to contribute with knowledge-based input to policies, management, energy strategies and more.

NTNU

Geir Walsø
Deputy Head of Department of Civil and Environmental Engineering

Faculty of Engineering NTNU

The former Department of hydraulic and environmental engineering at the Norwegian University of Science and Technology (NTNU) has been an active partner in CEDREN. The scientific activities of the centre have covered various branches of science, contributed to an excellent connection between research and education, and have indeed strengthened research collaboration between NINA, SINTEF and NTNU. The establishment of the first eleven FME's has been stimulatory measures to this multidisciplinary collaboration, but has also been an important entity to the industry and its commitment to basic research.

About 80 % of all engineers on master's level in Norway are educated at NTNU, as well as a very high share of PhD candidates in the technology field of which the industry employs roughly 70 %. The department's participation in CEDREN has helped ensuring a high quality in the education of master and PhD candidates, among other factors due to coupling master theses to ongoing PhD projects.

NTNU's current strategy expresses the vision: Knowledge to a better world. The faculty's mission in this context is contributing to meet global challenges of which providing food, water, sufficient and clean energy, and sustainable solutions to meet climatic and environmental changes are relevant CEDREN issues. In the current research strategy of the faculty, the department was given responsibility for the strategic focus area: Hydropower to Norway and the world.

The department's research group in hydraulic engineering has been a central and important contributor in performing research activities of relevance to hydropower. The hydraulic engineering laboratory and catchment field stations are infrastructures of great importance in this respect. Financial support from CEDREN has made it possible to invest in a rather unique, glass sided tilting flume, of which there are few in Europe. This flume has resulted in basic research activities as well as more applied projects. CEDREN has also given financial support to buy advanced scientific equipment for field use as well as laboratory applications. A total of ten PhD candidates has been provided money for through CEDREN, an important contribution to the department's scientific production.

The collaboration in CEDREN between NINA, SINTEF and NTNU has been useful for all of us as research partners, but also to the industry partners who have found valuable results through PhD and master theses, handbooks, user meetings and seminars. CEDREN has provided a solid base for future collaboration.

Statkraft

CEDREN has had a major impact on the national and international discussions concerning dilemmas related to the climate benefits of renewable production versus environmental impact from such operations.

Ragne Hildrum
VP Corporate R&D
Statkraft

How has Statkraft benefited from being a CEDREN user partner?

- Methods, processes and specific solutions for environmental design developed by CEDREN have been utilized in development work that Statkraft has been involved in.
- CEDREN has led to increased knowledge and competence within Statkraft organisation through the involvement of user partners in specific projects and through the general communication of results at conferences and seminars.
- Through the platform provided by the FME scheme, access to and collaboration with relevant research partners and relevant industry partners has been substantially improved.
- Through the education scheme in CEDREN for both Master students and PhD-students, CEDREN has improved recruitment and strengthened the competence base for the hydropower industry in general. This will also strengthen the access to qualified personnel for Statkraft in future recruitment.
- The innovation strategy in Statkraft is primarily influenced by market, technology development and Statkraft's business strategy. However, the CEDREN projects have been an important part of our R&D portfolio and several of the projects have had a good fit with themes in our current Hydropower R&D strategy.

How has CEDREN contributed to:

- CEDREN has had a major impact on the national and international discussions concerning dilemmas related to the climate benefits of renewable production from hydropower and wind power versus environmental impact from such operations. CEDREN has provided valuable evidence and new knowledge into these discussions, promoting both the sustainability of hydropower and wind power as well as future possibilities for these technologies in a global market.
- The knowledge build through CEDREN, and the dissemination of this knowledge amongst a broad range of stakeholders both nationally and internationally, has played a central role in raising awareness around the role of Norwegian hydropower in a future energy system. Nationally, CEDREN has contributed to position hydropower as the "backbone of the Norwegian energy system", and to challenge political awareness of the current strengths and future possibilities of hydropower in the Norwegian energy system.

CEDREN has also provided facts and increased the general awareness of the opportunities related to flexibility and storage capacity of Norwegian hydropower in a future European energy system. With the increasing need for balancing services and security of supply in Europe, CEDREN has provided insight and new ideas for the role of the hydropower system, and the need for increased transmission capacity and new cables to further positioning Nordic power production for the European power market.

More specifically and with even more direct impact and relevance for the industry in the short term, CEDREN has developed methods and tools on how to secure biodiversity and environmental friendly operations from hydropower and wind power. We would also like to mention the high degree of interdisciplinary skills CEDREN has brought to table through its work in technology, environment and society.

According to Statkraft, the methods developed by CEDREN to demonstrate the added value from multipurpose hydropower, the flexibility of the hydropower system and the environmental design of hydropower production demonstrated in Norwegian power plants, are all important contributions to broaden and clarify the perception of hydropower as a renewable production scheme that has a central role in the future climate friendly technology mix. Photo: Statkraft

The collaboration between different stakeholders has been fostered through the involvement of various user partners. This collaboration has united the perception and acceptance of what is good environmental design. This has also enhanced and improved the collaboration and dialogue between industry, regulating governmental bodies and social stakeholders to jointly find solutions that optimize both biodiversity and power production, and to find good and sound compromises where needed.

There are ongoing discussions related to the sustainability of hydropower in the international renewable community. The methods developed by CEDREN to demonstrate the added value from multipurpose hydropower, the flexibility of the hydropower system and the environmental design of hydropower production demonstrated in Norwegian power plants, are all important contributions to broaden and clarify the perception of hydropower as a renewable production scheme that belongs in the future climate friendly technology mix. By being present on relevant conferences and scientific arenas, and through international research collaboration, CEDREN has given input to IPCC, IEA , EERA and political processes in the Energy Union on these matters. The Norwegian hydropower system as a global asset has been introduced and promoted on the international political agenda.

What are the most important CEDREN results, and how has Statkraft used them?

- One of the most important results for Statkraft is the systematic methodology described in "Handbook for environmental design in regulated salmon rivers". The method has been tested in the regulated section downstream of Viforsen power plant, in Ljungan river. We have obtained an increased knowledge related to the extent and quality of habitat available from Viforsen power plant and down to the sea. Through this knowledge we have got a foundation to make decisions with regards to both power production and the environment. We can even find win-win solutions for how production can be planned in relation to the salmon life cycle. The methods developed may become a standard for other rivers where increased water loss or reduced product flexibility may be imposed due to new requirements. The knowledge is essential for Statkraft's forthcoming challenges.

- Another important result from CEDREN is increased insight into government controlled processes and professional opinions that can affect Statkraft's business in the long term - for example through requirements, taxes or fees. This insight, gives us the opportunity to influence such processes and opinions. CEDREN has, as an example, resulted in publications which show that hydropower does not have a high water consumption in energy production, as opposed to some other findings.
- Statkraft has also obtained increased knowledge about flexible hydropower operations on the ecology of rivers. This will provide a better decision base both for existing power plants and new ones. The project has made recommendations for environmental adopted hydropeaking, but the topic reunions debated due to conflicting intrests.

How well has CEDREN succeed in the dissemination and targeted communication of processes and results?

- CEDREN has had an ambitious communication strategy, implemented through targeted communication measures to a broad spectre of stakeholders. The centre has achieved impact both on the national and international arena through its extensive network established within the research community, political stakeholders and governmental bodies. Good communication and involvement of user partners throughout the lifespan of the centre has built a useful platform for further interdisciplinary collaboration between industry, research community and other stakeholders in years to come.

Agder Energi

Svein Haugland
Environmental coordinator

Agder Energi

Through our active participation in CEDREN, we have got access to new knowledge about how to handle environmental challenges caused by hydropower production, and participated in fruitful interdisciplinary discussions. Our involvement in CEDREN has strengthened the cooperation with the scientific community as well as with other companies.

The role as user partner has given us the opportunity to implement new knowledge about how to combine the interests of salmon production and power production. The concept of environmental design, which is a method to evaluate, develop and implement measures to improve living conditions for salmon populations in regulated rivers, while taking hydropower production into account, has been of special importance to us.

Agder Energi has implemented environmental design, as well as other methods and tools developed in CEDREN, in the Mandal watercourse. We expect positive effects both on energy production and on the conditions for the reproduction of salmon

In our view, CEDREN's work to get acceptance for environmental design within the industry, research community and public authorities has been a great success.

In our opinion, there is no doubt that CEDREN's effort to build knowledge about balancing benefits from renewable energy production with impact on the local environment has contributed to the realization of CEDREN's vision "Renewable energy respecting nature".

Per Øyvind Grimsby
Superviser watercourse environment

Sira-Kvina kraftselskap

Sira-Kvina kraftselskap

Sira-Kvina kraftselskap has been one of CEDRENs most active user partners. In summary, the solutions and new knowledge developed in CEDREN are of great value to us.

Like other hydropower companies, we are facing new environmental requirements through the EU Water Framework Directive, the Norwegian Biodiversity Law and the on-going revision of hydropower licenses. In addition, we are developing new hydropower projects.

To us, the concept of environmental design developed in CEDREN has been of great importance, and we are using environmental design strategically in order to reach our goals. By using the methods developed in CEDREN, we have been able to identify bottlenecks in the rivers and develop effective solutions.

Sira-Kvina has been involved in many of the CEDREN-projects through concrete case studies. In our view, the case studies is the main reason why CEDREN has been so valuable to us.

CEDREN is viewed as highly credible by its user partners and the public authorities. In our view, this is because CEDREN has been a multidisciplinary research centre and always willing to pick the best researcher for the job. By working closely with the user partners, CEDREN has develop innovative solutions to balance the benefits from renewable energy production with the impact on the local environment. In other words, CEDREN has developed new solutions to some of the problems that we and the rest of the industry face.

Rune Flatby
Director Licensing Department

The Water Resources and Energy Directorate

The Water Resources and Energy Directorate

Norway has a long history of renewable energy production. The modern Norway was built and industrialized when we started to utilize rivers and waterfalls to produce electricity. In order to meet climate change challenges and increased introduction of variable renewable energy technologies, we need to further develop Norway's hydropower resources. Norwegian hydropower has large capacity in storing energy which is crucial for the future energy system. Interactions between hydropower and new technologies may contribute to further value creation both in Norway and in Europe.

Managing and developing both the existing hydropower system and new renewable energy technologies, have to rely on science-based knowledge about the power system, marked design, environmental impacts and technological solutions and opportunities.

CEDREN has given us valuable knowledge in several areas, and results from CEDREN are applied in the on-going revisions of hydropower licenses and in the implementation of the EU Water Framework Directive. The results from CEDREN in environmental design have shown us that it is possible to combine important environmental values with further development of hydropower production.

To NVE the new knowledge provided by CEDREN is important in the evaluation of all types of energy projects in order to secure sustainable use of Norwegian renewable resources.

The Environment Agency

The Agency, which is a significant user of research findings in many fields, has been following CEDREN though the whole centre period. Being a CEDREN user partner has given us the possibility of continuous research engagement in core areas of our governmental jurisdiction.

Torfinn Sørensen
Head of Section for water measures and energy

Norwegian Environment Agency

In our view, the combination of natural sciences, technical disciplines and social sciences in CEDREN have contributed to the success of CEDREN. Also, the overall scope of CEDREN, including both existing and new forms of renewable energy and the energy system level, has been fruitful. Giving substance to the rather fuzzy discussions on Norway as provider of balancing energy services may come out as one of the most lasting contributions form CEDREN.

Beyond the big questions, we use CEDREN results at a daily basis in various management tasks. To date, the CEDREN "Handbook for environmental design in regulated salmon rivers" has had the greatest practical significance. The measures recommended in the book will certainly facilitate increased natural recruitment of fish in regulated rivers, including establishment of new spawning areas and improved shelter for the salmon and sea trout populations.

The experience from implementation of the CEDREN results is so far limited and requires an evaluation of the long term achieved effects, by ourselves and in cooperation with the industry and the research teams involved in CEDREN. Our experience so far is very promising.

Over all, it is our clear impression that CEDREN has worked in line with its vision "renewable energy respecting nature", and that the centre has contributed significantly to solve challenges in the field of environment friendly energy production through research results, processes and by facilitating cooperation between the partners.

15 The role of the centre

In 2008, just before the launch of the first FMEs, climate change concerns began to work its way into the field of energy research. The belief in using fossil resources like oil and gas was still strong. The strategic vision for future energy policy in Norway was outlined in the first ENERGI21 report, released in February 2008. In the recommendations, five priority areas were defined: Efficient use of energy, Climate-friendly power, CO_2 neutral heating, Future energy system and Improved R&D framework. The main technologies seen for climate friendly energy were hydro, wind, solar and bio power. Hydropower was only briefly discussed, most likely reflecting the view that hydropower would not be an important future technology.

It is interesting to compare this to the updated ENERGI21 report released six years later in 2014. The attitude towards hydropower had completely changed. Hydropower and flexible energy systems were now both given top priority, even above the other four high-priority areas: Offshore wind, solar power, efficient use of energy and CO_2 handling.

Today, hydropower is acknowledged as a major source of renewable energy with high potential for creation of more jobs, increased production and value generation. In particular, using the large hydropower reservoirs for storing energy and balancing other renewables has become a major issue.

The climate impact and need for ecological and environmental design was clearly stated by ENERGI21. It is also pointed out that a good knowledge base and sufficient human resources with strong scientific and engineering background is necessary to achieve ENERGI21 goals.

We believe that the research in CEDREN and the strong focus on dissemination of results in many fora, may have contributed to the change in views and priorities, and thereby to the strengthening of the research on hydropower. In particular, we think the balanced "CEDREN-approach" combining technology, environment, economy and social values has been important. On one hand, CEDREN has shown great potential for using the Norwegian hydropower system as an integral part of the European energy system, and at a cost that is very competitive compared to other technologies. On the other hand, it is important to consider and mitigate possible negative impacts. CEDREN has developed methods and demonstrated that this can be done in an environmental-friendly way, sometimes even finding win-win solutions where both the power production and the environmental conditions are improved.

The term "environmental design" has been established and demonstrated not only for hydropower but also for wind power and power lines. Methods, models and tools to find the best sites for wind power plants and power lines integrating technical requirements, environmental impacts, economics and societal acceptance have been developed in CEDREN. Through the work related to governance, regulatory aspects and societal acceptance, CEDREN gives recommendations for an improved dialogue and decision making between renewable energy developers, the authorities, stakeholders and the public.

16 Future prospects

The HydroBalance project in CEDREN funded by the EnergiX program, will continue also in 2017, while the SafePass and SusWater projects will run throughout 2018. Their user groups will take over the role of the CEDREN Board, and www.cedren.no will be their main platform for online information.

The methods of environmental design of regulated rivers will be further developed with a broader scope in the research centre HydroCen, where the main research groups from CEDREN are engaged. The concept of environmental design is also a major part in the Horizon2020 EU project "FIThydro" on hydropower and fish on a European scale, where SINTEF Energi and NTNU are research partners, and Statkraft industrial partner. The methods of environmental design of regulated rivers have been developed into a "EVU-kurs", which again will trigger many applications and further developments of this method. As lessons in environmental design have been given in China and Romania, we also expect a wider use of the methods worldwide. Several projects to make CEDREN findings and results in environmental impacts of hydropower more directly applicable for water managers working to implement the European Water Framework Directive, are currently in progress.

The research groups at SINTEF Energi, NINA and NTNU, will continue to apply for relevant project calls from the Research Council of Norway and others to further test, enhance and document envrionmental design.

Photo: Atle Harby

www.cedren.no

Renewable energy **respecting** **nature!**

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CEDREN Centre for Environmental Design of Renewable Energy

FME Centre for Environment-friendly Energy Research