CenSES

CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

Final Report 2019

Centre for Sustainable Energy Studies

Editors: Asgeir Tomasgard
Original layout: Stine Mari Skeide, Marie Antonsen and Hilde Wormdahl
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Content

CENSES FINAL REPORT 2019

1. Foreword

Foreword from the Chair of the Board

The research in CenSES is now finalised and we can conclude that the centre has been very successful in creating national building blocks in the multi-disciplinary activities between economy, technology and social sciences. As Chair of the Board of CenSES and Director of NTNU Energy, I acknowledge that CenSES has played a vital role in the Strategic Research Area Energy as well as in Sustainability at NTNU and beyond.

A large number of final reports, publications, presentations as well as policy briefs for the public have been completed and CenSES has successfully achieved important new results, both at a national level and in an international context. It has been of utmost importance to synthesise the results into understandable knowledge and tools for politicians and the industry to make guidelines and solutions and for them to take action to achieve the goals of the Paris Agreement. Important in this aspect is the recruitment of Masters and PhDs educated in CenSES to operationalise the results in our own organisation.

Johan E. Hustad
Chair of the Board, CenSES

Foreword from the Centre Director

We started thinking of a national multidisciplinary social science-based research centre on energy transition in 2007/2008. CenSES started off in 2009, recognising the need for social sciences and the humanities (SSH) to play a more prominent role in the energy transition. To achieve this, we found out that two factors were crucial: Firstly, the SSH disciplines were in need of consolidation and more cooperation across disciplines like sociology, political sciences, innovation, economics and modelling. Secondly, there was a potential for increased cooperation between the SSH area and technology research. When CenSES received FME status in 2011, our capacity and capability to follow up on these two factors increased dramatically. In addition, bringing in around 20 partners from industry and government was essential to ensure and increase the relevance of the research. The results of this can be seen in the position papers and policy briefs described in this report.

Focus on multidisciplinarity, cooperation and relevance has made the researchers successful on the international arena, too. International research cooperation has been at the forefront of our agenda from the start, but the capacity and visibility CenSES has given us have lifted our international research. This is particularly noticeable in international cooperation on scientific papers, workshops and PhD schools, and in an explosion of the number of joint European projects under the H2020 framework that we participate in.

In the course of the last year, we have increased our focus on the dissemination of the research to the general public. One of the more successful initiatives is the website "ungenergi.no" made by youths for youths. The relevance of the pages reaches further, though. Have a look at www.ungenergi.no and judge for yourself. Also, researchers in CenSES and friends from other FMEs and from the industry have made the Enersikt/Enerview podcast, a series of short overviews and discussions on some of the main challenges we are facing in the energy transition.

For the next eight years, we will continue the CenSES multidisciplinary tradition in the new FME NTRANS-Norwegian Centre for Energy Transition Strategies. For now, I would like to thank all partners for the excellent cooperation and welcome them to equally good cooperation in the future.

Asgeir Tomasgard
Centre Director, CenSES

2. Summary

The vision of CenSES is "Knowledge for a sustainable energy transition". It is our objective to conduct research that supports public and private decision makers in strategic decisions and policies that will promote environmentally friendly energy technologies and lead to a sustainable energy system. The centre combines the strength of leading Norwegian social science research institutions with the support of international partners and important Norwegian stakeholders to provide a knowledge base for how to handle these challenges when developing national energy and climate policy and for strategies of innovation and commercialisation.

An important aspect is understanding and researching how economic, political, social and cultural aspects of society change with the introduction and development of low carbon technologies and solutions, or how existing structures hamper change. CenSES has defined five focal research areas:
RA1: Policymaking and transition strategies
RA2: Energy systems and markets
RA3: Economic analysis
RA4: Innovation and commercialisation
RA5: Scenario development

During its lifetime, CenSES has produced 260 peer reviewed papers, 468 conference presentations and contributed to more than 440 presentations for the CenSES user partners and target groups. Centre affiliates have been involved in supervising over 244 master students and 63 PhD students and post docs during its lifetime. The PhD candidates are working in the industry and business (16%), in research (69%) and in the public sector (9%). Most of the master students work in the private sector.

The PhD school in FME CenSES had a strong component of international cooperation through compact courses with international professors and students, winter schools on management of uncertainty in energy systems as well as summer schools on social sciences and humanities in the energy transition. More than 450 students from 30+ countries have participated, building invaluable international networks for CenSES researchers.

Participation in international networks has benefitted the research. Examples are the Transatlantic Forum, the Singapore-China Energy Forum, the Science without Borders programme in Brazil, the Energy Technology Systems Analysis Program (ETSAP) of the International Energy Agency (IEA) as well as the new European Energy Research Alliance (EERA) programme e3s on Economic, Environmental and Social Impacts co-founded by CenSES researchers. This has led to a high share of international co-publication and has given us the chance to establish more than 23 new international projects in H2020, ERA-Net and other platforms.

There are numerous ways in which scholars have benefitted from CenSES being a research centre. The social sciences and humanities research (SSH) in Norway have been consolidated, increasing collaborative efforts through joint publications and a high number of projects. The centre has also strengthened the collaboration with technology researchers, public agencies, businesses and the industry. It is our experience that a strong research community like CenSES, with its holistic approach to systemic innovation, increases our attractivity for external partners. The centre has increased both our capacity and our capability to synthesise and disseminate results. This can be seen in the Enersikt/Enerview podcast series, in ungenergi.no, in policy briefs and in a number of multidisciplinary position papers coming out of CenSES user cases, as well as in the broad participation in public discussions on energy transitions by CenSES scholars.

The user cases in CenSES bring together researchers from across the defined Research Areas to address specific topics. The research topics were decided upon in cooperation with the user partners in CenSES. Also, the user partners participated actively in the work. Here we list some of the results from FME CenSES sorted on the main objectives of the FME scheme.

Methods and models supporting policy and value creation.

A key contribution has been new insights in processes of policy production. Our studies have emphasised the generative capacities and potential of the public, and the many roles that members of the public and other actors might take on in the transformation of the energy system. Research shows that, to achieve radical transformative change, we should re-think the orchestration of citizens and social groups through innovation policies that recognise the importance of working to embed new technological solutions in society.

In energy systems modelling, we have developed a new class of multiscale models that include uncertainty of intermittent renewables in long-term analysis. This gives us new insight in the European energy mix and in Norway´s role. These methodological advances have led to new knowledge for energy and climate policy.

CenSES has studied different projections for energy demand in Norway towards 2050. The analysis shows the effect of different demand side measures in Norway. On the supply side, we have studied the role of Norwegian energy resources in Europe, with focus on hydropower, natural gas and offshore wind. All these may have a high value for Europe. Natural gas has the most uncertain future, while offshore wind is more attractive when the North Sea region is developed jointly with the other countries in the region.

Zero-emission transport will be key to Norway meeting its climate obligations. CenSES results show that it is possible to reduce emissions from transport enough to achieve this, but that we are not on that pathway.

New knowledge for innovation and value creation.

Our research on innovation and value creation focuses on how to build new industry based on renewable technologies. The work points to large possibilities, for example utilising our offshore competence, but it also points out challenges. It is important for the industry and for start-ups to get access to foreign markets and partners. For policy makers and business support schemes, it is important to think of industry development and energy policy, as they could go hand in hand. Support and incentives for the Norwegian energy transition should also comprise collaboration with Norwegian suppliers. The research also points out success criteria for how to achieve value creation from technology-oriented FMEs in industry-academia cooperation. Balancing different institutional logics and early clarification of expectations is of vital importance. Furthermore, the development of common arenas and anchoring of the cooperation at both the strategic and the operative level is crucial in order to create successful long-term cooperation between industry partners and the research centre.

3. CenSES vision and goals

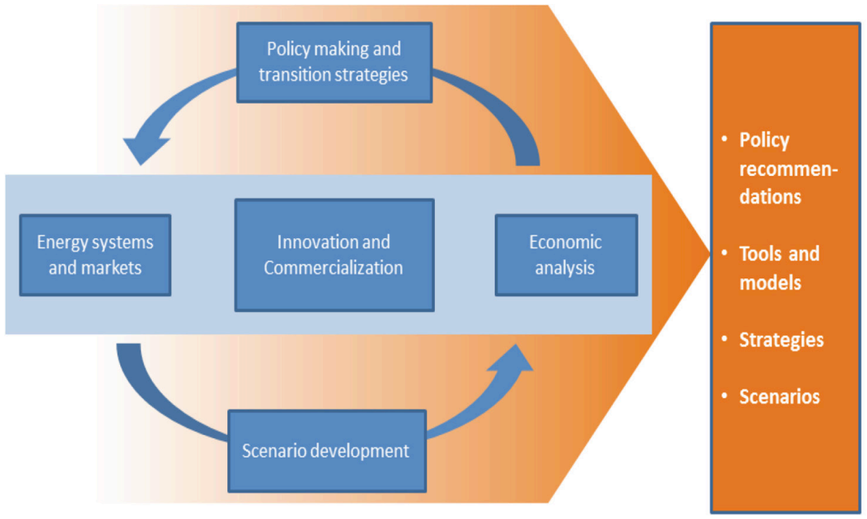
The Centre for Sustainable Energy Studies (CenSES) was established in 2009 by the research partners. In 2011, we received status as a national Centre for Environment-friendly Energy Research (FME) by the Norwegian Research Council and were joined by some 20 user partners and 10 international partners.

The objective of the FME initiative is the establishment of time-limited research centres which conduct concentrated, focused and long-term research of high international calibre in order to solve specific challenges in the field.

CenSES research integrates the following disciplines: energy systems and markets, industrial ecology, economics, political science, sociology, innovation studies and science, and technology studies.

FME CenSES vision:

Knowledge and engagement for sustainable energy transition



CenSES' research objective:

To conduct research that supports public and private decision makers in strategic decisions and policies that will promote environment-friendly energy technologies and lead to a sustainable energy system.

An important aspect of this is understanding and researching the economic, political, social and cultural aspects resulting from the introduction and development of renewable energy and environment-friendly technology and solutions.

CenSES defined five focal research areas (RA):

- RA1: Policymaking and transition strategies
- RA2: Energy systems and markets
- RA3: Economic analysis
- RA4: Innovation and commercialisation
- RA5: Scenario development

Within the framework of these areas, CenSES develops fact-based knowledge for strategic decisions by the government and the industry. This includes knowledge for a national energy and national and international climate policy and for strategies of innovation and commercialisation.

The involvement of user partners, consisting of both public and private decision-makers in Norway, has been pivotal for meeting this objectve. User partners have played a major role in the definition of cross-cutting user cases across the research areas as well as in the preparation of position papers.

The operatonal objectives of CenSES were:

Objectives for education and recruitment

- Develop master courses and a PhD school in social scientific energy studies.
- Educate 40 PhD candidates and post docs under the FME budget.
- Supervise at least 20-30 master students every year.

Relevance objectives

- Perform a number of scenario studies and user cases in cooperation with the user partners. Some targeted areas were: Model development and energy scenarios, Regulation and international coordination in energy markets, Quantitative and qualitative aspects of the development in energy use and features affecting future energy use, Climate and energy policy, and Innovation and value creation.

Dissemination objectives

- Disseminate results to the public through:
  - Yearly conferences
  - Workshops and seminars
  - Quarterly newsletters
  - High visibility in the news media
- Establish Innovation Forum in cooperation with the technology-oriented FMEs.
- Establish an Energy Strategy Board together with Technoport.
- Establish a public website: www.censes.no.

Publication objectives

- Present 150 papers on international conferences.
- Publish 120 articles in academic journals with peer review.
- Write 3 scientific books and 40 book chapters in edited books.

In addition to strictly academic dissemination through journals and scientific conferences, CenSES set itself a goal to publish results that could potentially become useful within energy policy making, as well as contribute to creating a better and broader energy discussion in society.

Did we meet the objectives?

In this report, we will summarise the main achievements within CenSES research areas, our stakeholder cooperation and international collaboration, focusing on the objectives above. In short:

CenSES quantitative objectives were met with good margin. When it comes to the relevance of the centre, we decided early in the process to strenghten communication and dissemination. It is not enough for the research results to be relevant, they also need to be communicated and appreciated by the stakeholders. One of the lessons learned from the first phase of the work was that shorter and synthesised reports were of high value for the user partners. Hence, the work on user cases, research synthesis, policy briefs and position papers was given more resources and higher priority.

In this report we will summarise the main achievements, illustrating also how relevance was ensured.

4. Facts about CenSES

CenSES was hosted by the Norwegian University of Science and Technology (NTNU) with the following research partners:

- Norwegian University of Science and Technology (NTNU)
  - Department of Industrial Economics and Technology Management (IØT)
  - Department of Interdisciplinary Studies of Culture (KULT)
  - Department of Energy and Process Engineering
- SINTEF Energy Research
- SINTEF Technology and Society
- Institute for Energy Technology (IFE)
- Norwegian School of Economics (NHH)
- Institute for Research in Economics and Business Administration (SNF)
- University of Oslo, Centre for Technology, Innovation and Culture (TIK)
- Høgskulen på Vestlandet
- Vestlandsforsking

User partners: Powel, BKK, Differ, ENOVA, Hydro, Innovasjon Norge, Sør-Trøndelag Fylkeskommune, Miljødirektoratet, NORWEA, Sparebanken Sogn og Fjordane, Sogn og Fjordane Fylkeskommune, Sognkraft, Equinor, NORWEP, Statnett, NVE, SFE, Bergen kommune.

International partners: Lancaster University, Linköping University, Tsinghua University, The University of Edinburgh, University of Maryland, TNO, DIW Berlin, Fraunhofer ISI, IEA-ETSAP and Pacific Northwest National Laboratory.

The centre has had a total budget of 288 mill NOK. The Norwegian Research council contributed with 80 mill., the research partners 95 mill., user partners 37 mill. and the host institution 76 mill.

National research partners

User partners

International research partners

Organisation

CenSES Management Group


Asgeir Tomasgard
NTNU


Marianne Ryghaug
NTNU


Tomas Moe Skjølsvold
NTNU


Kari Aamodt Espegren
IFE


Gunnar Eskeland
NHH


Roger Sørheim
NTNU


Erling Holden
HiSF


Hans Jakob Walnum
Vestlands-forsking


Stefan Jaehnert
SINTEF


Olav Wicken
UiO


Kjetil Midthun
SINTEF


Raquel Santos Jorge
NTNU


Tove Svenning
NTNU

The management group had members from each of the research partners and represented all disciplines. They played a major role in promoting cooperation in the centre by:

- Collectively preparing the overall research agenda for the centre as a whole
- Jointly preparing the conferences, workshops and seminars
- Making sure the user cases reflected the disciplines of the centre
- Building a centre culture and creating relations across disciplines

CenSES Board


Johan Hustad
Director, NTNU Energi


Hanne Wigum
Manager, Renewable Technology, Equinor


Frode Rømo
Research Director, SINTEF


Fulvio Castellacci
Centre Director, UiO


Lasse Torgersen
Head of Department, Hydro

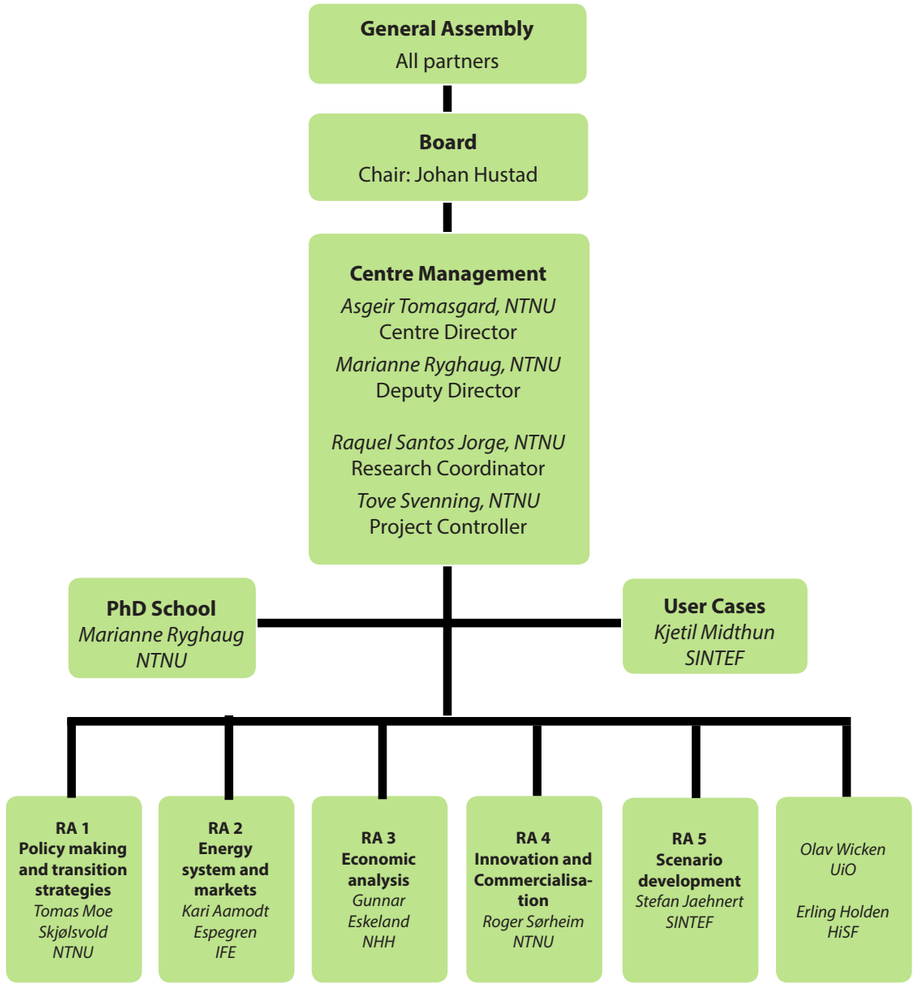

Mette Bjørndal
Professor, NHH


Ola Lingaas
Vice President, SFE


Mattias Hoffman
Research and Development Program Lead-er, Statnett


Arne Lind
Department Head, IFE


Petter Hersleth
Head of Strategy, Enova



FME CenSES centre organisation chart

PhD candidates with financial support from the centre budget


Martin Anfinsen
NTNU


Veronica Araoz
NHH (2012)


Lisa Maria Assman
NHH


Vegar Lein Ausrød
NTNU (2016)


Øyvind Bjørgum
NTNU (2016)


Xiaomei Cheng
NHH (2015)


Linda Ellingsen
NTNU (2017)


Evengelos Kyritsis
NHH (2018)


Thomas Gibon
NTNU


Geoffrey Gilpin
Vestforsk/UMB (2016)


Mads Dahl Gjefsen
UiO (2015)


Ole Inge Gjerald
Vestforsk/NTNU


Jens Hanson
UiO (2013)


Daniel Haugstvedt
NTNU


Puck Hegeman
NTNU


Robert L. Jomisko
NTNU (2015)


Susanne Jørgensen
NTNU


Karen Byskov Lindberg
NTNU (2016)


Sylvia Lysgård
NTNU


Tuukka Mäkitie
UIO


Hector Marañon-Ledesma
UIO


Johannes Mauritzen
NHH (2012)


Patrick Narbel
NHH (2014)


Håkon Normann
UiO (2017)


Hilde Nykamp
UiO (2015)


Ha Thi Bich Pham
UiO (2016)


Hilde Reinertsen
UiO (2016)


Bente Johnsen Rygg
HiSF/NTNU


Vivek Sinha
NTNU


Christian Skar
NTNU (2016)


Zhonghua Su
NTNU


Trine Unander
NTNU


Eirik Swensen
NTNU (2015)


William Throndsen
NTNU (2016)


Hans Jakob Walnum
Vestforsk/AAU (2015)


Tyson Weaver
HiSF/NTNU (2016)


Shiyu Yan
NHH


Ni Yuanming
NHH


Elisabeth Svennevik
Uio


Marie Byskov Lindberg
UiO


Iren Tvedten
UiO


Christine Mee Lie
UiO


Schimon Grossman
NHH


Yewen Gu
NHH

Post docs with financial support from the centre budget


Ekaterina Bjørnåli
NTNU (2016)


Chiara Bordin
NTNU


Jens Hanson
UiO


Erik Haugom
NTNU


Marius Korsnes
NTNU


Liste Lucìa
NTNU (2017)


Johannes Mauritzen
NHH (2015)


Adela Pages
NTNU (2014)


Stefan Pauliuk
NTNU (2015)


Parmita Saha
HiSF (2014)


Christian Skar
NTNU (2017)


William Throndsen
NTNU


Gerardo Perez Valdés
NTNU (2014)


Ola Edvin Vie
NTNU (2013)


Tyson Weaver
HiSF/NTNU


Håkon Normann
UiO


Anders Arvesen
NTNU


Ruud Egging
NTNU


Erik Andreas Sæter
NTNU

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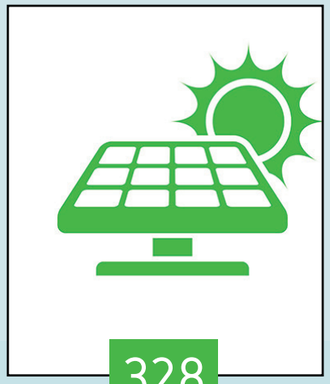
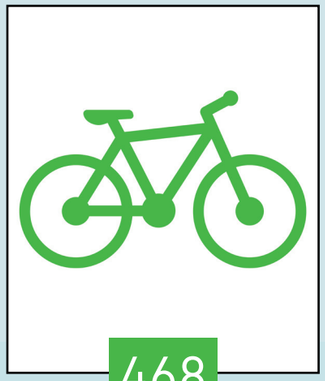
CenSES in numbers



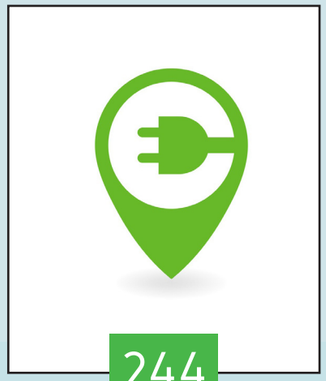
328

Articles published in scientific/scholarly journals or series or anthologies



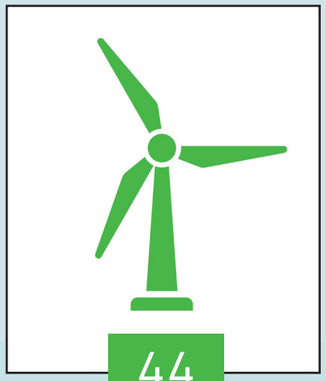
468

Conference presentations



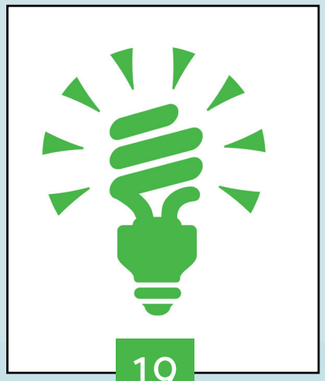
244

Master students



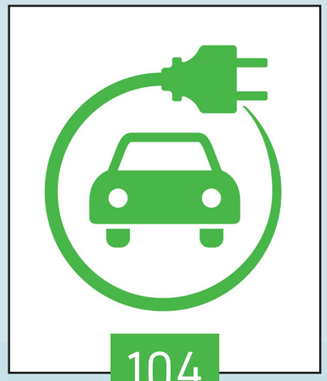
44

PhD-candidates



19

Post doc



104

Conferences or workshops arranged

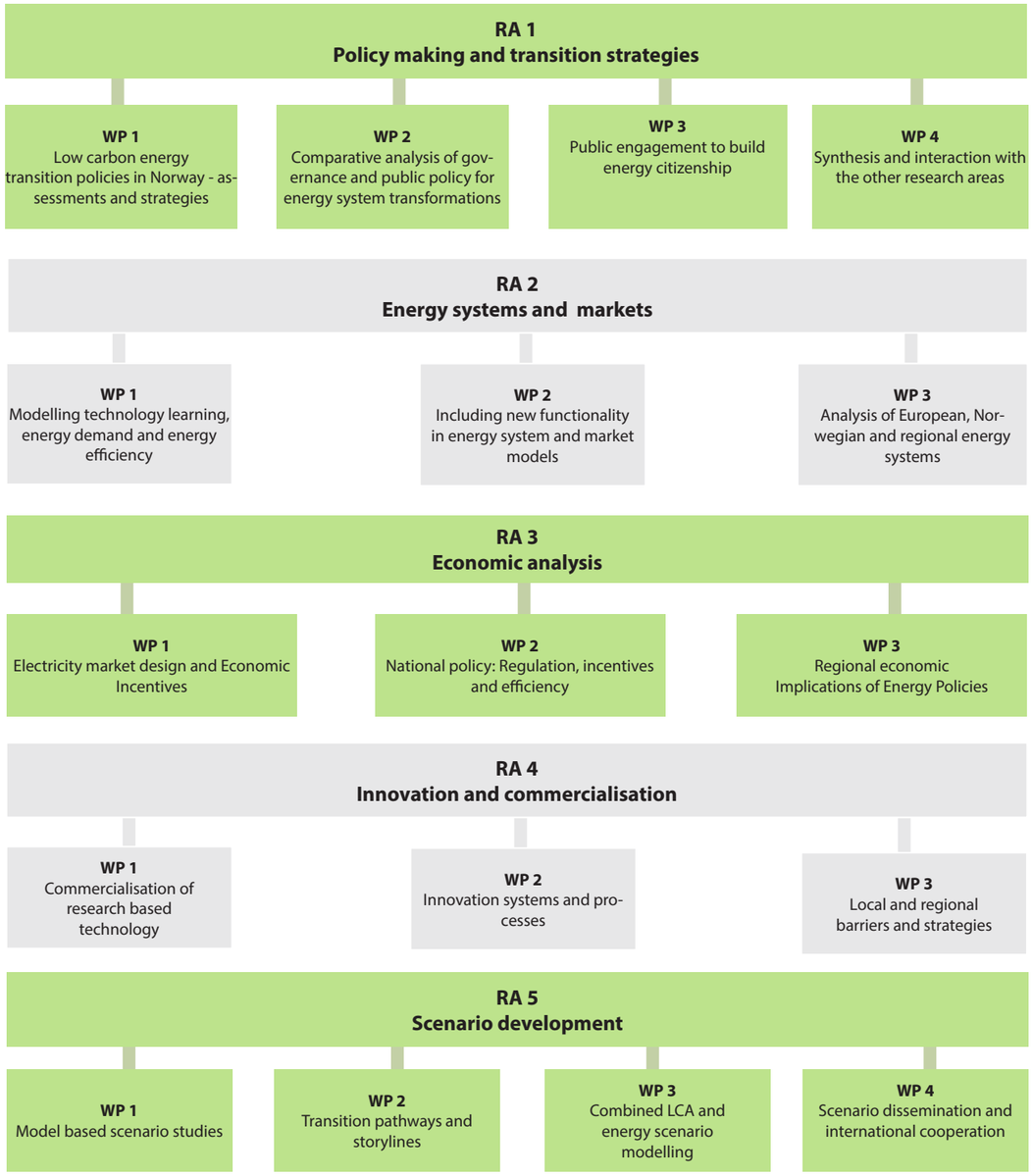
5. Results - Key Figures

	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
Publications										
Articles published in scientific/scholary journals or series	10	16	30	37	38	42	33	43	11	260
Articles published in anthologies	4	6	12	9	7	21	2	2	5	68
PhD dissertations		2	1	2	6	9	6	5	2	33
Conference presentations	25	51	76	66	36	59	55	83	17	468
Monographs published			1	2		1	1	1		6
Reports, notes, etc	7	5	10	18	13	8	8	3	44	116
Dissemination for user groups										
Presentations for project target groups	24	101	64	62	31	57	70	26	5	440
Popular scientific dissemination										
Popular science publications (articles/books, books/articles in the public debate)		3		6	3	7	2	2	1	24
Blog essays	15	12	3	3	1	2				36
New publication in the media (newspapers, radio, TV etc)	18	19	9	66	55	47	66	34	37	351
International activities										
CenSES researchers on exchange for one week or more	3	17	10	12		2	6	7		57
Guest researchers visiting the centre for a week or more		4	8	13	7	5		3		40
Project meetings with international partners	1	3	6	3		16	10	3		42
Conferences arranged	2	9	6	5	9	3	5	4	2	45
Workshop arranged	3	9	6	12	3	8	14	12	6	73
CenSES researchers plenaries, key notes and tutorials		3		2	14		11	5	1	36
Lectures given at foreign institutions by CenSES researchers		8	2	7	4		7	6		34
Visiting lecturers to the centre	1	19	8	9	3	13	1			54
Recruitment and education										
Courses developed		2				1	2	1		6
Master students	20	25	33	56	16	21	50	23		244
Winter/summer school arrranged	2	3	2	2	1	1	1			12
Projects/products/processes/services/models/technologies										
New innovation projects for public sector/industry				2		1				3
New research projects	19	6	10	7		10	6	6		64
New International projects started	1	1	2	3	1	7	2	2	4	23
New models			1		1					2

6. Research

Here follows an overview of the research in FME CensSES based on the 5 research areas, user cases and position papers.

Overview over the Research Areas (RAs) and associated Work Packages (WPs)



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RA1: Policy making and transition strategies

The goal of RA1 was to "strengthen the knowledge base for the formulation of policy for energy transitions at national, regional and local level" by engaging in basic and applied research. We have defined policy makers broadly, focusing on actors who produce strategies that seek to influence how other actors across levels navigate with respect to the much-needed energy transition. In many ways, we were ahead of our time, since later landmark efforts within the EU (such as the H2020 platform Shape Energy) have shifted their focus from "policymakers" to the broader notion of "policy workers".

We have studied the processes of policy production through probing the work of committees that write governmental action plans, the work of environmental NGOs as transition actors, the role of consulting engineers, business, industry, incumbent actors and innovators, as well as the role of researchers and research institutions in progressing or slowing down the energy transition.

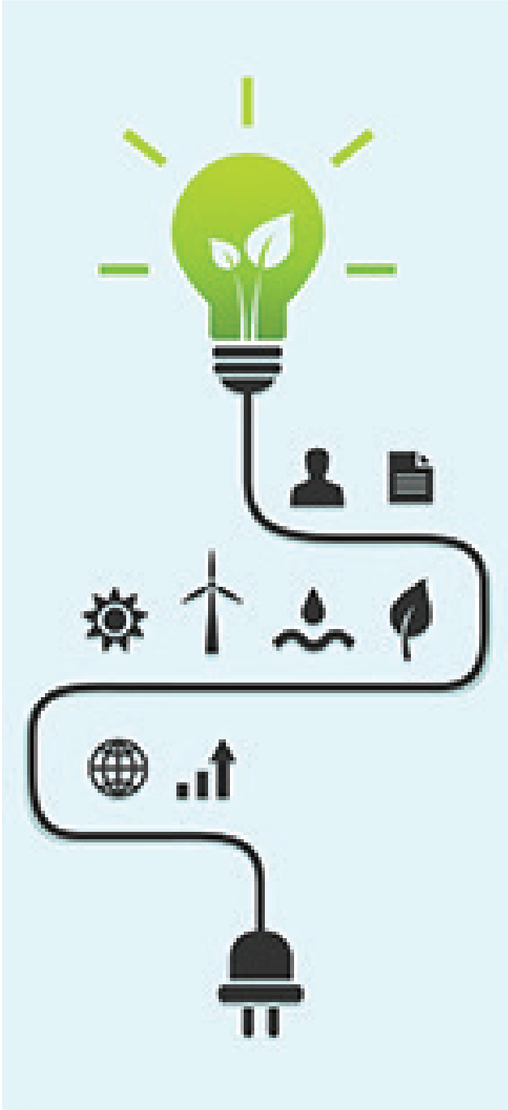
An important aspect has been to examine public involvement in energy transition processes. This work has been developed amongst other things to deepen our understanding of the conditions for nurturing energy citizenship. This has been a key contribution of our work to the international social scientific literature on energy transitions (see, Ryghaug et al. 2018). This is another area where CenSES has been ahead of its time, illustrated by Horizon Europe's recent call for large projects on precisely "energy citizenship".

In what follows, we will highlight three key research streams emerging from RA1, and show how these have contributed to moving the social science energy research frontier.

Moving beyond innovation and deployment in studies of technology policy

A lot of RA1 research has been conducted in critical but constructive dialogue with traditional perspectives addressing two concerns. Firstly, how to design policy that stimulates technology development? Secondly, how to develop policies that stimulate cost-efficient uptake of such technologies in markets? As a contrast, RA1 research has moved "downstream" to ask questions about how specific technologies can become embedded and integrated in the practices, organisations, markets and culture of particular societies. This is a challenge for low carbon technologies in Norway because of the pervasiveness of oil and gas as symbolically important for Norway's self-understanding as an "energy nation", and as central to Norwegian wealth and welfare.

Hence, Norway is a challenging case for new low carbon technologies. With this as a backdrop, RA1 researchers have probed a series of sites where different actors work to deploy and implement new energy technologies while struggling to succeed. Offshore wind is one example, covered through two doctoral theses within this research area (Heidenreich 2014; Normann 2017) as well as a series of papers (e.g., Steen & Hansen 2014, Hansen & Steen 2015, MacKinnon et al 2018). Official Norwegian strategies such as Energi21 (2007) highlighted future offshore wind parks as an important future industrial avenue for Norway, partly rooted in the idea that developing an offshore wind industry might mobilise much of the same competence, and many of the same resources that have been central to the success of Norwegian offshore oil and gas. Offshore wind parks have been pointed out as preferable to onshore ones because many actors believe they will be less controversial. Despite strategic policy push and widespread availability of relevant competence and technology, offshore wind parks are nowhere to be seen on the Norwegian coast. The question is: why?



Offshore wind development in Norway suffers from a narrow technology policy focus, at the same time featuring a dominant policy paradigm of cost-efficient measures. The key policy strategy has been to grant R&D funding, e.g. through two large FME centres. This, however, is arguably the end of the story. The involved R&D institutions and their industrial partners have largely been left with the task of innovating and commercialising offshore wind technology. There have been no policy efforts to support a home market for offshore wind electricity, and the industry has repeatedly pointed to a lack of government support (Hansen and Steen 2011). Meanwhile, researchers and research groups have been reluctant to take on active roles in making offshore wind parks a reality in Norway, beyond talking to their industry partners (Heidenreich 2014, 2018).

The Norwegian offshore wind R&D initiatives came at a time when future expectations in the oil and gas industry were meagre. In 2009, the oil prices dropped dramatically. Hopes were high that resources and technology from oil and gas could quickly find their way to offshore wind. Indeed, CenSES research indicates that 40% of all Norwegian companies who target offshore wind also work within oil and gas or the maritime sector, while 80% of the companies mobilise technology or knowledge from this sector. Hence, there is a level of industrial flexibility involved, which allowed many actors to focus on offshore wind while times were difficult in oil and gas. Things quickly changed, however, as a new oil boom ensued. Many actors lost interest in offshore wind and refocused on oil and gas activities (Normann 2017).

This story illustrates the need for a focus beyond technological innovation, and calls for an analysis that seeks to understand how work within a broad range of sites and amongst a broad range of actors across society is needed to embed technologies in established societies (Sørensen 2013). Within RA1, we have conducted analyses related to this with respect to a multitude of technologies such as bioenergy, CCS, hydrogen, solar cells, and electric vehicles. We observe a lack of sustained engagement from politicians, policymakers and industrialists to transform new technologies into ingredients of an energy transition (Swensen 2015). Electric vehicles are the main exception. There is little doubt that perceived dependence on oil and gas contributes to this lack of engagement (Korsnes & Sørensen 2017).

Transition actors and their strategies

The practical politics of energy and sustainability transitions are often formulated and enacted beyond traditional sites of party politics. An example of this can be found in our studies on how consulting engineers work to advance sustainability transitions. This actor group is often overlooked in research, but they exercise considerable influence in many environmental decision-making processes. Sørensen, Lagesen and Hojem (2018) highlight the importance of understanding how this group, which mediates governmental requirements, environmental politics, cost considerations, and professional standards, engages in mundane transition work. They do so in four ways. Firstly, through sustainable technological problem solving, which involves practicalities of issues like calculation and design. Secondly, through persuasion work to induce customers to go for more sustainable options. Thirdly, through mediation work to clarify how regulations, rules and standards might be met. Fourthly, by engaging in institutional work to influence governmental policies and regulations.

Over the last years, many of our efforts to study transition actors and their strategies have been anchored in research projects that seek to develop smart and distributed energy solutions, often incorporating small-scale renewable energy technologies, energy storage and demand side management measures such as new price structures, feedback or automation.

Such endeavours often explicitly seek to test and verify both a set of technological configurations, and a set of new social roles and activities on behalf of a range of actors. In a recent effort to synthesise across nine case studies from Austria, Denmark and Norway (Ornetzeder et al. 2018), we identified five issues that such projects seek to work towards resolving. The first issue is ensuring local anchoring, acceptance and support. The second is making price incentives that work in practice. The third is balancing electricity generation and demand. The fourth is involving technology users, and the fifth is integrating solutions from such projects in broader energy systems.

We have conceptualised the work in and around projects that seek to advance smart or distributed energy solutions as a set of collectives of orchestration (Skjølsvold et al 2018). In our work, we have been interested in how actors within policy making, technology design, as well as R&D and innovation have worked actively to produce new roles for households within distributed energy systems. Hence, this is an instance where transition actors

work as social engineers in attempts to reconfigure our future relationship to electricity. Typical goals include producing flexible consumption, active consumers, prosumers, behaviour change, and energy community.

The implications of such work for the development of future policy strategies is substantial. Today, such projects tend to reproduce ideals that are anchored in strong networks of policies, institutions, research programmes and new technologies that understand and support household participation as being about changing individual consumption and behaviours. On the other hand, networks around other, and potentially much more radical, changes are weaker. Hence, in order to achieve more radical transformative change, we should re-think the orchestration of citizens and social groups through innovation policies which go beyond testing new technologies. Instead, experimentation to increase participation in distributed energy transitions should probably also entail testing new ways of producing policies, standards and regulations, and new modes of working within R&D.

From public acceptance to energy citizenship

An important aspect of transition work is the relationship to 'the public'. A lot of RA1 work has dealt with the relationship between transition strategies and their many different publics. We have probed such issues through studies of technology use, studies of how the public makes sense of and perceives aspects of the energy transition and broader climate change issues, and through studies of different ways that the public engages with energy transition efforts.

This work has been done in dialogue with research that frames the public as "end users" or as "consumers", or perspectives that highlight "acceptance" as a barrier to technology diffusion. By contrast, our studies have emphasised the generative capacities and potential of publics, and the many roles that members of the public might take on. For example, our research into households' engagement with electricity consumption shows that while price is a concern, it is only one of many. In general, people frame household consumption of electricity as a set of moral issues. For example, the increased focus on climate change has made such concerns part of the moral reasoning around electricity use (Aune et al. 2016). Further, many people strongly link social justice to energy transitions. Social justice in this respect means that financial and other strains shall be distributed equally among the population, so nobody can buy their way out of political measures (Aune et al. 2016).

Such issues have also been important in our studies of technology users, such as our extensive work on the introduction of electric vehicles in Norway. We have analysed this in terms of policy development and innovation, but our most recognised contributions internationally look at the role of technology users in interpreting, making sense of and promoting electric vehicles as a feasible technology in Norway. An important aspect of these studies has been to highlight the importance of the material aspects of technologies that are used, and how engaging in new practices through such technologies might become part of processes that feed into changing environmental attitudes, and enabling new forms of pro-environmental behaviour. We have seen this amongst early adopters of electric vehicles, many of whom are not mainly motivated by environmental concerns. However, many of them report that through their use of an electric vehicle, and the many situations of dialogue that they become part of due to driving an EV, forcing them to "read up" and acquire new knowledge, they have become more interested in environmental or energy issues. This often also spills over into an interest in other emerging energy technologies such as solar panels.

Our work on public relations about climate change highlights that there is a demand for tangible action strategies. What should one do if one wants to act upon climate change as a citizen? Technologies such as electric vehicles provide one such option for many Norwegians. Smart energy technologies, solar cells, and electric bikes are three other examples. These technologies are all materially localised close to where people live, or are even owned by citizens. They also serve to link practices across infrastructures and realms of mundane life. Finally, such technologies share a trait in promoting diversification, as opposed to the highly standardised relationships within centralised energy systems. While these traits of the technologies cater for the embedding of the technologies within a wide array of life styles, they also serve to politicise certain aspects of mundane life, and hence trigger forms of engagement beyond private consumption.

Within this field of research we have also identified significant opportunities for experimenting with both policy development and technology development in a systematic way. A recommendation from RA1, in this respect, is to find ways of developing technologies and instigating transitions that engage publics as citizens and collectives, rather than merely as consumers.

RA2: Energy systems and markets

The main outcomes from the research in RA2 are education of PhD students, development of new functionality in energy system and market models, improved data for long-term energy analysis, and use of the new and improved models to analyse user cases, scenarios, specific energy policy options and impact of development in new technologies.

Research groups from CenSES have been actively involved in modelling and analysis performed by the European Energy Modelling Forum (EMF), in IEAs Energy Technology Systems Analysis Program (ETSAP) as well as in the Zero Emission Platform.

Analysis in this research area includes a wide range of topics, stretching from the impact of electrification of the petroleum and transport sector, analysis of different market design for power, bidding models for the power market, impacts on the electricity market, impact of the increased share of intermittent energy to impact of energy and climate policy on the energy system. Here we present some examples of studies and the main model developments. Models and methodology developed in RA2 have also been important for the analysis in the position papers and scenario studies developed in CenSES (presented later in the report).

Carbon neutral Scandinavia

The study of a carbon neutral Scandinavia demonstrated a cost-optimal transition towards a carbon neutral energy system in Scandinavia (Denmark, Norway and Sweden) in 2050. The analysis was done with a stochastic TIMES model. The stochastic TIMES model was developed to be able to include the short-term uncertainty of renewable electricity generation and heat demand. With more renewables in the electricity generation mix, it is important to focus on how to handle the short-term uncertainty, related to intermittent generation, in strategic planning.

As the Scandinavian electricity sector already has a high share of renewables, carbon neutrality requires extensive changes in other parts of the energy system, including the building, transport and industry sectors. In the analysis we have assumed a Scandinavian energy system which to a minimum extent depends on external markets, which implies no import of bio fuels, no CCS in the power sector and no hydrogen production from natural gas steam methane reforming. We also assume a conservative expectation of the future implementation of energy efficiency.

The results show that a transition to a carbon neutral Scandinavia requires major changes to the energy system. It will involve a significant electrification of the end-use sectors, especially in transport. The electricity capacity needs to be about doubled compared to the current capacity level, and the share of intermittent wind power and PV in the electricity generation mix will increase considerably. Further, the analysis shows that hydrogen is the dominant fuel used in the transport sector, and it is cost-optimal to invest in both inflexible hydrogen production and more costly flexible hydrogen production. Due to the increased electricity consumption in the end-use sectors, there will be no net electricity export to the rest of Europe in a carbon neutral energy system in Scandinavia.

Solar power in Norway

In this study, researchers in RA2 have cooperated with researchers in RA1 (policy) and RA4 (innovation) to understand how Norway can take a leading role in solar power, both with respect to the development of the technology, and in terms of installed PV capacity. On the one hand, we have used the energy system model TIMES-Norway to analyse how energy demand, technology costs, and technology learning can impact the future energy mix, and on the other hand we have analysed the feasibility for change in a society perspective. A starting point for the discussion is our motivation to combine quantitative and qualitative studies, to understand how we can use different disciplines to supplement and enrich the research. Where the energy system models are based on assumptions for future development, the qualitative

studies often are concerned with the past or the present. We have used dialogue between researchers to challenge both traditions.

There are a number of parameters that have an impact on the future development of PV technology in Norway, some of the main of which are future electricity price, electricity market design, technology costs, long-term policy instruments and support schemes, building regulations, degree of automation, new energy storage technologies and public opposition towards large-scale power plants and transmission grids.

The impacts of extensive implementation of Zero Energy Buildings

Two CenSES PhD candidates, Karen B. Lindberg and Pernille S. Seljom, cooperated on a study on an extensive implementation of Zero Energy Buildings (ZEBs) in the Scandinavian energy system. ZEBs are identified as one of the remedies to meet the 20-20-20 goals of the EU, and according to the EU directive on buildings (EPBD), all new buildings shall be nearly ZEBs from 2020. A ZEB is a high energy efficient building that produces, on an annual basis, as much renewable energy as it consumes. Mostly, the on-site renewable energy production comes from solar power (PV) integrated in the roof and façade of the buildings. As ZEBs in a nordic climate also consume electricity during winter when PV production is low, the electricity market will act as a seasonal storage which serves the building with electricity in winter, and receives electricity from the building in summer. The aim of the work is to investigate the impact of ZEBs on investments in the Scandinavian energy system, and it is performed by using the TIMES energy system framework, which covers investments and operational decisions in the building, transport, industry, electricity and district heat sectors.

The findings show that the reduced heat demand of ZEBs, and their increased PV electricity production, lower the electricity price within the Scandinavian countries. This makes investments in wind and CHP less profitable, but increases the use of electricity for heating purposes. The results show that the Scandinavian region will increase its net export to Europe. Overall, the findings of this research indicate that on an aggregated system level, we see no big challenges for introducing ZEBs. However, further analysis of grid implications on regional and distributional grid level is needed.

Model development and analysis

EMPIRE
The EMPIRE model is a Euopean power market model originally developed in CenSES to study the impact of short-term variability on long-term investments in power production. It is unique in the sense that it can represent both long-term uncertainty (like demand trends and policy) as well as short-term uncertainty (load, inflow, intermittent generation). It is used to study the interplay between flexible energy generation, like hydropower or natural gas with CCS, and intermittent renewables towards 2050.

TIMES
The long-term optimisation model TIMES was developed to represent short-term uncertainty. To our knowledge, this is the first time a TIMES model has been extended to include short-term uncertainty by stochastic programming. The methodology was introduced in CenSES and in related research projects, and the model and the methodology have been used in several studies of low carbon transition of the future energy system.

MULTIMOD
MULTIMOD is a long-term multi-sector multifuel energy system model which can analyse strategic behaviour. It is one of the first equlibrium models with this functionality. It has been used in several European and global studies, and was developed in cooperation between DIW Berlin and NTNU.

REMES
REMES is a computable general equilibrium (CGE) model developed in CenSES RA2 and RA3 as well as in the spin-off projects REGPOL and Norwegian Energy Roadmap 2050. It is a regional economic model that has been hardlinked to TIMES. Both a static and a dynamic version of REMES exist. One of the main features of REMES is to calculate economic consequences of energy policy and how they impact energy demand.

RA3 Economic analysis

RA 3, Economic Analysis, saw learning from the technological spheres, including other FMEs and the other research areas (RAs), as its responsibility, to tie these together and focus on policy analysis. An emphasis that from the outset distinguished CenSES from other research on climate and energy policy was how policy would be linked to developments in Europe. Norwegian policy and policy debate was at the time somewhat conflicted between a dogma of global cost effectiveness (no mitigation in Norway can be justified if there are cheaper options elsewhere) and Norway's intentions to be part of European mechanisms like the Emission Trading System (ETS), a green certificate system jointly with Sweden, and cross border trades in electricity.

The question raised in the CenSES strategy from the proposal stage was: 'Can Europe maintain its mitigation commitment, and if so, what course will it take?' An early answer (for instance Statnett's Autumn Conference, 2013) was that a shift starting in the electricity sector was forthcoming, and that costlier generation would likely be accompanied by low electricity prices. The reasons, highlighted in CenSES's research also in partner conferences and publications, were a) because expanding renewable generation was forced and subsidised rather than cost driven, b) because recession in Europe was making compliance with ETS limits cheaper, as demand for electricity and other emission intensive commodities was shifted down.

Analysis in CenSES and outside at the time also showed the pressures that would mount if Europe was on a tighter mitigation schedule than the rest of the world: carbon leakage and adjustment costs. This led Europe (including Norway) to pursue policy instruments moderating these pressures: free quotas for industries in international competition (metals, for instance), support rather than cost-driven mitigation (feed-in-tariffs and green certificates, for instance), and CO_2 compensation. As a consequence, the green shift was forthcoming in European generation in ways that did not raise power prices and emission costs (by much). For Norway, this meant a focus on territorial emissions, which – as it could not cut emissions in generation – had to focus on energy use, especially in the fossil based transport sector, and which had to seek expansion in renewable energy without high emission costs to drive it. CenSES research pointed out, for instance prior to 2014, that offshore wind was promising but would need more support than green certificates. Such support was not politically sellable, in part because industrial interest was sufficiently busy with petroleum.

Globally, Copenhagen 2009 through Paris 2015 combined to reduce the emphasis on global cost effectiveness and raise the focus on own territorial emissions. This entails some shielding of competitively oriented sectors (free quotas and CO_2 compensation), and greater focus on energy efficiency (buildings especially), on power generation, on transport, and on R&D and innovation. For Norway, this meant much tougher policies for road traffic than anywhere else. One interpretation of why Norway puts more pressure on automobiles than most countries is that Norway has no automobile industry. An interpretation of Norway's emphasis on electrification is that only Norway already has emission free electricity generation. An interpretation of Norway's emphasis on CCS is that fossil owning nations will benefit most from the only strategy that allows a longer life for fossil combustion. On policy analysis, RA3 emphasised that Norway's use of the car registration tax to price CO_2 intensity was outside the textbook but very clever, pushing buyers and sellers together to find CO_2 leaner solutions to their needs. RA3 also emphasised that the electric vehicle support policies could better have been technology neutral (using a then even higher CO_2 fee), but also that the two targeted approaches have been producing results, as they should, since costs per ton are and have been high.

The leadership aspect emphasised in RA3 research is that it is hard to justify such policies unless one is motivated by others following. This is also illustrated by RA3's proposed two-pronged approach to maritime shipping. Maritime shipping is quite generally emission effective (energy effective) in the sense of lower emissions per ton-mile and passenger mile than its alternatives in the air, on rails or road. Thus, emission reductions must be sought in such a way as not to harm maritime shipping's competitiveness. The two-pronged approach points out that in shielded coastal trades, as our ferries, one may seek radical (zero carbon?) solutions for demonstration and leadership. In competitive international transport markets in contrast, it is more important to show that moderate interventions can compete: global emission reductions lie in sales volumes. Research contributions have thus emphasised that apart from new technologies (hydrogen, for instance), solutions such as speed, size and slenderness should also be sought.

Another challenge highlighted in RA3 research is the spatial and temporal dimension of the renewables transition. This has entailed an emphasis on transport, but also a heavy emphasis on renewables and electricity markets. A rising share of renewables in Europe also means a rising share of intermittent power, with new requirements on operators and market design. Obvious implications are markets with more nuances, more sophistication, as with greater spatial and temporal resolution, insurance, portfolio and options. Clear results are that if wind intermittency is costly, then less so in a system with large reservoirs, like Norway's and its neighbours, depending on transmissions as well as market design and policy instruments.

Limitations in the portfolio approach from finance academically lie in such areas as the distinction between variability and predictability, as well as in the costs of integration (as in transmission investments). RA3 research has explored such questions as the additional benefits of electricity market integration, and an example finding is that yes, one can already see Danish wind in Norwegian reservoirs (Mauritzen). Narbel points out that policy instruments used in support for renewables in Europe (certificates, feed-in-tariffs) could be improved by differentiating according to whether a particular wind location supplies power when the system needs it, similar to what the spot market tariff does. Chronopolous and Eskeland, and Lillestoel utilizes Bayesian analysis and options aspects to highlight how one learns about a wind location's quality.

The quality, functioning and design of electricity markets has been an important area of research. With more intermittent power, a question is whether markets become more susceptible to market power with greater temporal and spatial resolution. RA3 research examples as diverse as hydropower, gasoline retail, and stylised networks are supportive of this possibility.

Trade of physical power usually takes place in a sequence of organised markets, from the day-ahead until shortly before the operating hour. In addition, there are balancing markets, which aim to correct real time imbalances between supply and demand and to make power flows compliant with power system constraints. In practice, market clearing often occurs through the use of mathematical optimisation models, which maximise the socio-economic surplus (or minimise costs) based on purchase and sales bids from the players in the market. An important element in the market design is how limited transmission capacity is taken into account when power is traded. This can be done in different ways in different markets, but ultimately the power flow must be within permitted limits in the power system. With more renewable production in the power system, uncertainty increases and an important question is whether the models for market clearing should take explicit account of the uncertainty.

State secretary Jens Frølich Holte and Gunnar Ekseland. Photo: Natalia Flórez Mejía.

In RA3 and the associated INTREPED project, we have explored how variability and predictability can be quantified, and we have discussed different ways of clearing day-ahead and balancing markets in a situation with considerable uncertainty and/or variability. Using historical data from existing and planned wind park locations in Norway, we have studied how forecasting errors depends on factors such as time of year/day and wind speed, how wind speeds in different locations are correlated, and how spatial correlation affects the quality of ensemble forecasts. Using simple examples, today's (myopic) market design based on sequential sub-markets, has been compared to a centralised market clearing, based on the solution of an integrated stochastic optimisation problem. Stochastic market clearing may provide higher welfare than today's market solution, due to better coordination, but such a market model assumes that the players agree on the uncertainty related to, for instance, future wind, and some players may have incentives to deviate from the system-optimal plan. When market clearing takes place using an integrated stochastic optimisation model, it is not necessarily beneficial to model the detailed power flow in the day-ahead part of the problem, since these constraints are taken care of in the real-time parts of the model anyway. When the day-ahead and the balancing markets are cleared sequentially and separately, the conclusion is the opposite. Considering pricing, this way of formulating the stochastic market clearing has some beneficial properties, such as revenue adequacy in every scenario (i.e. that the system operator or marketplace receives a revenue that covers the cost in every scenario) and cost recovery on average (i.e. that all market participants have their total cost covered on average over all scenarios). Thus, it is possible to clear day-ahead and real-time markets by means of an integrated stochastic market clearing model that takes into account uncertainty in renewable generation and demand, improving expected welfare and resulting in prices that make the market operator go in balance economically and let the other market participants cover cost in expectation. The market clearing model and pricing mechanism have been tested on real world data using the New Zealand power system.

RA4 Innovation and commercialisation

CenSES RA4's overall aim was to create knowledge of the process of making a transition to sustainable and renewable energy sources. Such a process is complex and multifaceted, and implies the development of novel technologies and user practices, the introduction of policy measures and regulations, as well as the entry of new firms and industries that produce and adopt new technologies. RA4 made use of insights from the field of innovation and entrepreneurship studies to examine how new technologies emerge; how they become commercialised, produced and marketed; and how they are used in Norway and internationally. These questions relate to how multi-scalar energy transition processes involve change on several levels. These changes encompass the entry of new firms, formation of new industries and embedding new technologies in differing regional (local), national and supranational contexts.

Academic impact

CenSES RA4 has performed very well when it comes to publications in peer reviewed journals, not only in numbers but also in quality, through publications in target journals like Research Policy, Industrial and Corporate Change, Journal of Cleaner Production, Journal of Business Research, Technological Forecasting & Social Change, Industry and Innovation and Economic Geography. Further, we will highlight the strong involvement of master's students (more than 40 master's theses from this research area) and also pre-seed support of companies started by students.

However, the most important academic impact from RA4 is probably the contribution to develop a new generation of researchers focusing on development and commercialisation of new renewable energy solutions. In RA4 we decided early on in the centre period to support the development of a multidisciplinary research group of talented researchers from five different institutions connected to the centre. We can now observe that this generation of researchers plays a key role in bringing the social science view into several technical SFI/ FMEs. These researchers create and get regional, national and international funding to their own research ideas. Further, we can also observe that this new generation of researchers plays a key role in new large research initiatives like FME NTRANS and the SFI circular economy initiative. Overall, this means that CenSES has contributed significantly to the creation of several strong research groups with the focus on innovation and commercialisation issues of making the transition to sustainable and renewable energy sources.

Highlighting some research findings

A research team from CenSES performed a 5-year longitudinal study of university – industry cooperation in research centres (6 technical FMEs). This unique study was based on more than 100 interviews with research and industry partners and secondary sources like yearly reports, web pages and mid-way evaluations. Key findings are:

- Cooperation between industry and researchers is demanding and early clarification of expectations is of vital importance.
- Formal and informal arenas to create common ground facilitate long-term fruitful cooperation.
- Industry actors and research centres must dedicate time and resources at strategic and operative level.
- Industry actors with previous cooperation with universities and research institutes are better in implementing knowledge from the centres.
- Power balance between centre and industry actors is a key issue in order to facilitate co-creation of innovations.

Another example of research in RA4 is the study of how incumbent firms contribute to the energy transition processes. These firms have often been stereotyped as 'locked-in' to socio-technical regimes. This research provides a more nuanced and improved understanding of incumbents in established energy sectors and their extent of involvement in other (niche) energy sectors. Providing inter-temporal dimensions, this research covers incumbents' diversification activities beyond their primary sector both in the past (cancelled activities), present (ongoing activity in secondary sectors) and future (ambitions of diversification), and also distinguishes between producers and product/service suppliers. By incorporating insights on firm diversification, this research sheds new light on the complex transformation processes associated with sustainability transitions. Empirical results show considerable heterogeneity in incumbents' responses to changing selection pressures, which can be explained by recognition that windows of opportunity are opening and some incumbents see potential to leverage their resources and capabilities to capture value in new niche energy sectors in both domestic and international markets.

Another example is the RA4 related project RELEASE. This project follows the concept of sustainable development in which three dimensions must be balanced: economic, social, and environmental. Applied to the local effects of renewable energy projects, these dimensions are interpreted as an ambition to create economic value locally, to balance the social consequences of these effects for different local stakeholders, and to reduce local environmental effects. In this project they acknowledged that in 2017 it was 30 years since the UN Report Our Common Future was launched. The report put the term "sustainable development" on the international agenda and the report still has the authoritative definition of the term. They invited 15 international experts to two workshops in Oslo (2017) and Ottawa (2018) to discuss what had happened after 1987 and what challenges sustainable development represents today. Three topics appear to be central: (1) environmental limits; (2) justice, needs and development; and (3) transformations and transitions. Environmental limits link to ideas such as "planetary boundaries", population growth, consumption, and economic growth. The academic output from this work is a book by Edward Elgar in 2019 under the title: "What Next for Sustainable Development - Our Common Future at Thirty".

CENSES FINAL REPORT 2019

RA5: Scenario Analysis

The main objective of RA5 is to provide scenario driven knowledge and analyses to policy- and decision makers to aid in the development and evaluation of sustainable energy strategies. RA5 has contributed both to methodological progress in scenario studies as well as the development of a number of CenSES scenarios. We here present an overview of the methodologies developed in RA5 before we then present CenSES scenario study.

Linking LCA analysis with Integrated Assesment and sector models

Life cycle assessment (LCA) offers a systematic framework for attributing environmental impacts that occur in product supply chains to the product itself. In this way, LCA captures potentially important impacts that are neglected in other types of assessment tools that only cover direct impacts. At the same time, LCA has traditionally been static and micro-oriented, lacking the forward-looking optimisation perspective and macro-orientation of many energy system models (ESMs).

Within CenSES RA5 and co-supported by other projects (NFR ESBLET, EU FP7 ADVANCE), researchers at the Industrial Ecology Programme (IndEcol) have explored various approaches for LCA and ESMs to interact. The interaction can go in both directions: ESM procedures or results can be incorporated into LCA, and coefficients derived from LCA can be incorporated into ESMs and vice versa.

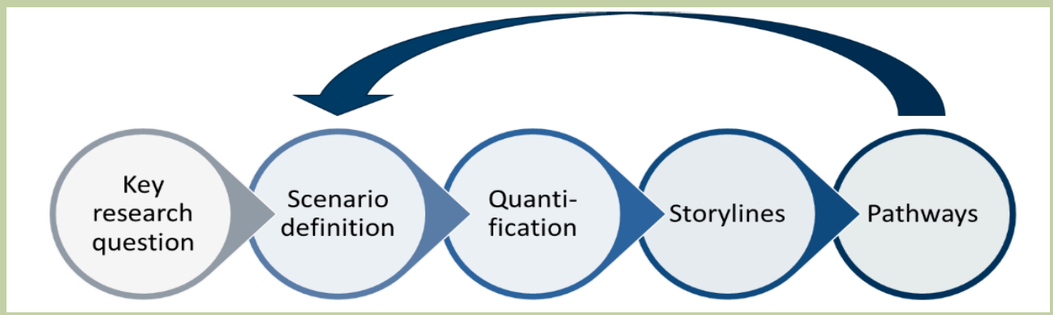
Linking of energy system models and integrated asessment models

The Links project performed in the eraly days of CenSES was pioneering in linking the Integrated Asessment Model GCAM to EMPIRE in cooperation with CenSES partner Joint Global Change Research Centre (PNNL). The purpose was to let the GCAM policy output, demand profiles and commodity prices serve as guidelines for development of energy supply and technology deployment in regional energy systems.

Later, this was adapted into analysing CenSES scenarios where GCAM was linked with EMPIRE and EMPS in order to analyse European and Norwegian impacts of Global socio-economic pathways.
This methodology breaks down results from a global perspective towards countries in Europe, with higher geographic, temporal and sector resolution. It allows the establishment of a framework for the energy scenarios given by different global developments, including emission levels and emission reductions paths from a global to a regional (European) perspective.

Pathways, storylines and scenarios

As a part of the CenSES scenario process, we have developed a five-step iterative procedure. Rather than focusing on quantitative scenarios only, we develop qualitative storylines for som of these, based on input from the other research areas. In these storylines, the researchers will tell similar stories about the future, guided by the quantitative scenarios. This methodology was successfully tested in the user case about "Energy demand projections towards 2050" and will be conducted for selected scenarios. The idea is to supplement the quantitative results with stories that support the quantitative dimension with credible descriptions of development from a policy and socio-economic perspective. The storylines will provide increased understanding of the social and political feasibility and implications of the scenarios. The combined storylines and quantitative information will be named transition pathways. This methodology has been successfully adapted to the H2020 project SET-NAV and will also be included in the new H2020 project Open-Entrance.



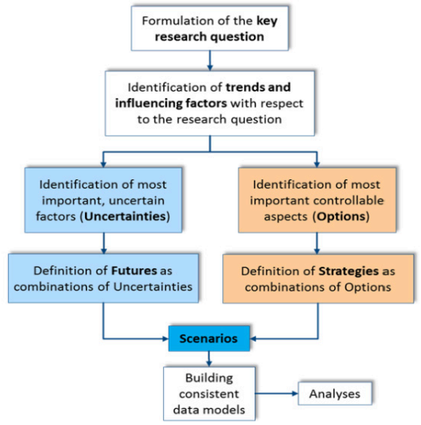
CenSES scenario methodology

The CenSES scenario process starts with a bottom-up approach in cooperation with the user partners, to ensure stakeholder engagement and relevance. The established scenarios result from a combination of defined futures, which have a European/global scope and a set of strategies, which have a Norwegian focus.
A future is a possible development / prospective state of the system. It is the combination of various uncertainties, which mostly comprises EU / global developments that Norwegian society has rather limited or no influence on.

The five futures developed in the CenSES studis are:

- Grass roots – A mitigation driven by local communities
- Fossil society – Relies on advanced technological solutions
- Green governance – Institutional driven mitigation efforts
- National ways – National concerns and well-being in focus
- Green globe – Common mitigation efforts within and across countries

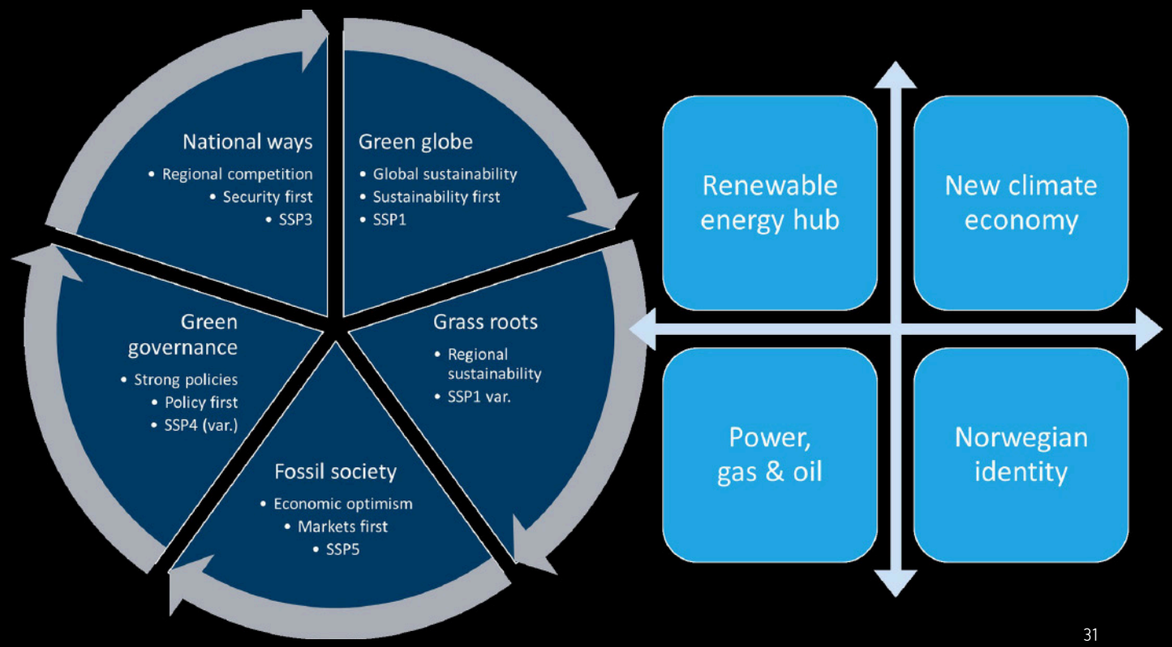
The strategies are the combinations of various options which the target group for the analyses can influence. In the context of the CenSES energy scenarios, this mostly comprises decisions with a Norwegian focus. The specification of the strategies was done in two main steps, as for the futures.



The four CenSES strategies are:

- Renewable energy hub – Export of RES and flexibility sources
- Norwegian identity – Domestic energy use to preserve economy
- Power Gas & Oil – Value based on export of all energy resources
- New climate economy – Carbon neutral economy based on domestic RES

Combining futures and strategies provides a large number of scenarios, where two of these are chosen for the further quantification process.



CenSES scenarios

In the quantifcation process the CenSES scenarios are aligned with IPCC's Shared Socioeconomic Pathways: SSP1 and SSP3 respectively.

- Green Globe - Sustainability (SSP1) describes a world in a transition to a significant greener and more environmentally friendly future.
- National Ways - Regional Rivalry (SSP3) describes a world with increasing focus on national and regional challenges and increasing competition between regions, including trading barriers.

The key research question for the scenarios were "How can Norway contribute to the global reduction of GHG and meet its climate targets for 2030 and 2050, while ensuring value creation within the framework of the energy system? Where can Norway be a leader and contribute to sustainable value creation based on its particular advantages?"

The following main conclusions were draw from the scenario assessment:

- Different global socio-economic pathways and climate targets have a significant impact on the development of the energy sector in Europe, including electricity.
- The development of negative emission technologies and the level of global cooperation affect how much, how fast and where greenhouse gas emissions are reduced.
- A faster technology development causes a postponing of emission reduction, as it relies on the availability of negative emission technologies, increasingly to the end of the century.
- Accounting for variability of iRES and a higher geographic resolution affects the resulting electricity generation mix, including a higher share of dispatchable power plants and less power generation from iRES.
- Due to the climate policy, fossil-based power generation without CCS is substituted with CCS and iRES power generation is used to supply the increase in electricity demand.
- The sum of greenhouse gases originating from the power sector is not decreasing from 2020 to 2050 but a much larger share of this CO_2 is captured in 2050.
- Due to the utilisation of gas power plants with CCS, there is an increasing demand for gas in the European power sector in both scenarios.
- While there is a doubling of generation capacity, there is a quadrupling of cross-border transmission capacity in the European power system.

Position papers

Nurturing new technologies

Edited by Markus Steen (SINTEF) and Tyson Weaver (NTNU)
Contributors: Øyvind Bjørgum (NTNU), Gard Hopsdal Hansen (NTNU), Jens Hanson (UiO), Tomas Moe Skjølsvold (NTNU), Roger Sørheim (NTNU)

The key topic of this position paper was the development of renewable energy (RE) technologies in Norway, or involving Norwegian actors. The case reflects upon the conditions for development and deployment of RE technologies in Norway, drawing on key arguments and factors with empirical research undertaken in RA4 (and RA1). This position paper was developed with input from CenSES user partners from three dedicated workshops. Despite substantial variety of approaches in RA4, the various points of departure for specific (empirical) research projects can all be linked to a shared interest in innovation and processes of industrial change and transformation. Another common feature is that technological development is not seen to be the result of technological innovations per se. Instead, the development of RE technologies is considered as part of broader processes encompassing change and innovation in organisations, business models, framework conditions (including regulation and policies) and systems.

Development of new renewable energy technologies has been and is an important policy ambition in Norway. In the context of nurturing new technologies, it is especially important to distinguish between the development of new technologies and their deployment. There are important synergies in learning and knowledge development to be gained from seeing deployment and development in tandem. This is because 'technology push' and 'market pull' processes are both important, mutually reinforcing drivers of renewable energy.

Because framework conditions are crucial for RE technological development and deployment, many contributions in RA4 have touched upon the role of (lacking) policy instruments, either directly or indirectly. Therefore, this position paper also draws upon insights generated in CenSES RA1 on policy making and transition strategies. Reflecting the use of broad perspectives on innovation, research in RA4 has gone beyond the role of energy policy instruments (e.g. types of subsidy schemes for RE) to also look at the role of industry and innovation policies that may directly or indirectly support technological development.

The common Norwegian-Swedish elcertificate market

Kari Aamodt Espegren, IFE, Arne Lind, IFE, Eva Rosenberg, IFE, Per Ivar Helgesen, NTNU/Enova, Asgeir Tomasgard, NTNU, Kristin Linnerud, HVL/CICERO, Stein-Erik Fleten, NTNU, Ove Wolfgang, SINTEF

A study in RA2 has summarised the research in CenSES related to the common Norwegian-Swedish electricity certificate scheme. The electricity certificate market was established in 2012 to increase the renewable electricity production. Risks and uncertainties related to the certificate scheme have influenced investment decisions in Norwegian wind power and hydropower since the scheme first was discussed in the Norwegian Parliament. CenSES researchers have analysed and discussed different types of risks, as well as the cost efficiency of the scheme and the distribution effects. Norway and Sweden share a combined goal of establishing 28.6 TWh new electricity production based on renewable energy by 2020. Producers of renewable electricity receive one certificate per MWh generated for a period of 15 years. Electricity suppliers have a statutory duty to buy green certificates, and each year the market participants with

an obligation to buy green certificates must redeem certificates to fulfil their obligation according to a yearly quota. This creates the demand for green certificates.

The main risks related to the electricity certificate scheme was addressed:

- Risk related to volume: Will the renewable production goal be reached? And will it be reached in a cost-effective manner?
- Risk related to price: The certificate scheme was introduced to reduce risks related to rate of return for the investors; however, this implies that the certificate price at least covers the difference between the market price of electricity and the cost of new electricity production. The certificate price is market based, and as such uncertain.
- Risk related to policy: Will the design of the certificate scheme influence the profitability? And will there be a continuation of the scheme?
- Risk related to distribution effects: Who will win and who will lose with this new policy instrument?

Based on this research it is our view that the design of the certificate scheme is an effective instrument to ensure implementation of new renewable electricity production. However, the certificate scheme is not cost efficient and it does not divide the risk between authorities and private actors in an optimal way. As a consequence, it is possible that not the best renewable energy projects have been built.

The research at CenSES shows that the electricity certificate scheme results in a welfare loss in Norway. The actors that have the highest welfare loss are the existing power producers, as they do not receive certificate price for the electricity production, while the new power producers that receive the certificate price, will win. However, this total welfare loss will be reduced if Norway increases the power export. If new power production is combined with increased Norwegian power demand, the result will be an increased welfare for all actors, both the existing and new power producers, and the consumers.

Energy demand projections towards 2050

Kari Aa. Espegren, Eva Rosenberg, Erling Holden, Olav Wicken, Marianne Ryghaug, Knut Holtan Sørensen

TAs opposed to most other European countries, Norway has no official, public energy projection. We have therefore developed an energy projection towards 2050, with openness to data and detailed discussions of parameters and resulting energy demand. It is not a prediction, but a projection, with assumptions based on discussions among the CenSES partners. The objective is to have a platform for further analyses within CenSES and other interested users, where assumptions can be openly presented. The intention is to develop alternative paths based on future discussions, as a way of improving the knowledge of how to achieve a sustainable future energy system.

The analysis gives an understanding of the high uncertainties about future energy demand. Four scenarios are presented, all presenting a possible future, and the total energy use differs with about 65 TWh in 2050. The electricity consumption differs with approximately 45 TWh from the lowest to the highest use in the four scenarios. Main parameters varying in the scenarios are the levels of industry activity and energy efficiency implementation as presented in Table 1. The reference scenario is based on an industry activity at the present level and minor implementation of energy efficiency.

A two-step methodology is used where the demand of energy services is calculated first. This is input to the energy system model TIMES-Norway that calculates the energy consumption. The calculated use of total energy and different energy carriers highly depend on the assumptions used in the analyses. The demand calculations are based on the development of drivers and indicators of each demand sector. A major driver is the population projection that is based on the medium national growth of Statistics Norway 2012. The assumptions are discussed with CenSES-partners, and the authors have full responsibility for the results and conclusions presented in this paper.
In the reference path, final energy consumption increases by 30 TWh to about 250 TWh in 2050. The increased electricity consumption is 21 TWh to 134 TWh in 2050. Implementation of profitable energy efficiency measures can reduce the final energy consumption by 4 TWh in total while the electricity use increase by 7 TWh (-2% and +6% respectively). In total, profitable energy efficiency measures including heat pumps can reduce the energy consumption in 2050 by about 23 TWh. Illustrations of some of these scenarios are included in this paper as "stories" describing literary how possible futures might become.

Hydrogen in a future low-carbon society

Asgeir Tomasgard (NTNU, redaktør), David Berstad (SINTEF), Odne Stokke Burheim (NTNU), Edd Anders Blekkan (NTNU), James Dawson (NTNU), Kari Aamodt Espegren (IFE), Per Ivar Karstad (NTNU), Terese Løvås (NTNU), Julien Meyer (IFE), Steffen Møller-Holst (SINTEF), Petter Nekså (SINTEF) Bruno G. Pollet (NTNU), Sigmund Størset (SINTEF) Kyrre Sundseth (SINTEF), Magnus Thomassen (SINTEF), Øystein Ulleberg (IFE)

As an energy carrier, hydrogen can contribute to the reduction of CO_2 emissions n a number of sectors, as this report, based on research in FME CenSES, FME MoZEES, NTNU, SINTEF and IFE, shows.

This report aims to give an overview of the roles hydrogen can play in a future low-emission society in order to reach the necessary emission reductions by 2030 in line with Norwegian climate policy. We look at where, how, and to what degree hydrogen technology can be implemented in order to become as efficient as possible a means to reach the goals of strongly reduced emission of greenhouse gases in Norway. We analyse sectors where hydrogen can be used fast, we assess barriers and possibilities, and how measures and politics can relate to this. The starting point of the report is that there is a need for new use of measures and policies that support climate goals for 2030, directed at hydrogen. At the same time, it is essential for decisions taken in this process to also be a step in the direction towards the 2050 goals. This will require interaction between the measures that are being taken for short-tem restructuring on the one hand, and long-term research and development to cover technology and knowledge gaps on the other hand.

Today, around 70 % of the total energy consumption in Europe is covered by fossil sources. Through the Paris Agreement (COP21) and EU's revised Renewable Energy Directive, Norway has committed to considerable greenhouse gas reductions and to more efficient and climate-friendly use of energy. The obligations involve a 40 % reduction of greenhouse gas emissions by 2030. The ambition lies at an 80-95 % emission reduction by 2050 compared to the reference year of 1990. On top of meeting the Paris Agreement, Norway shall be a driving force for international climate work, strengthen the climate settlement, and at he same time fulfil the kyoto protocol. The Jeløya political platform includes a commitment to zero-emission technology, and emphasises that the government shall have a holistic strategy for research, technological development and use of hydrogen as an energy carrier.

In addition to being a zero-carbon energy carrier, hydogen creates value since it can be stored and transported. This characteristic will become important in the future energy system with large amounts of non-adjustable renewable power. To be able to handle power surplus and power deficit, there will be a need for flexibility. Norway has good and natural prerequisites for producing hydrogen, both for home use and for exporation. This can be done through near-100 % renewable power or by further processing of natural gas combined with carbon capture and storage (CCS).

Prosumers`role in the future energy system

Ove Wolfgang (ed), Magnus Askeland, Stian Backe, Jonathan Fagerstrøm, Pedro Crespo del Granado, Matthias Hofmann, Stefan Jaehnert, Ann Kristin Kvellheim, Hector Maranon-Ledesma, Kjetil Midthun, Pernille Seljom, Tomas Skjølsvold, Hanne Sæle, and William Throndsen

Prosumers are people who consume some of the goods and services that they themselves produce. The supply of electric energy and flexibility services are two distinct services needed in all power systems. The prosumers considered in this document generate at least one type of power supply, for example through solar panels installed on the roof of their house or by a battery in their basement.

At the beginning of 2018, there were more than 1000 customers supplying surplus electricity to the national grid in Norway, and the growth rate is still high. It is difficult to forecast how many prosumers there will be in the future. At least three factors will be important for the future development:

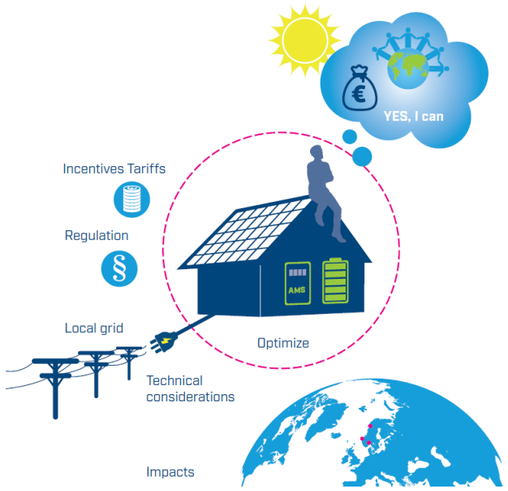
- Grassroots movements may lead to a considerable increase in the number of prosumers
- Continued cost reductions for solar panels and batteries
- The EU goal to achieve nearly zero-energy buildings (NZEBs), especially if it were prioritised over cost-efficiency in Norwegian implementations

This position paper presents research from a range of disciplines that mirrors the research carried out in the FME CenSES. The content of the position paper is represented in the following illustration:

This document gives a historical and qualitative overview of prosumers, insights into optimisation of prosumers' local energy systems, analysis of relevant regulation and incentives and tariffs, an overview of technical considerations for grid connection for own production, and quantitative simulations of energy system impacts. By contrast, the impacts of prosumers on distribution grid operations and enhancements are not the focus of this position paper.

The main findings can be summarised as follows:

- Existing prosumers in Norway have been motivated more by environmental concerns, technological interests, and self-consumption than by economic incentives.
- Smart meters have lowered the threshold for becoming a prosumer.
- Return on investment has been low for prosumers.



- Currently, batteries are not a cost-effective technology to lower peak electricity demand. It is less expensive to utilise flexibility in ventilation, electric boilers and heating. PV production (i.e. solar panels) in Oslo will reduce the need for transmission grid expansion to the city to a very little extent.
- A capacity-based grid tariff, which has been suggested by the Norwegian Water Resources and Energy Directorate (NVE), will make it less profitable to invest in solar panels, and will give stronger incentive for flexibility. Wind power and PV as types of varying renewable generation are complementary technologies for demand response. Additional amounts of one of them will increase the value of the other. Additionally, demand response will lower the need for backup electricity generation capacity. Different types of varying renewable generation are substitutes.
- In the EU and the EEA, national regulations for energy solutions in buildings should promote cost-efficiency. NZEBs are promoted, but it is not clear how they should be defined or how they should be handled if they do not become cost-effective.
- The local distribution system operator (DSO) should be involved in the process when a customer wants to invest in a PV panel to avoid instabilities in the electricity supply for the surrounding area.
- One of the main barriers for new prosumer business models is the lack or immaturity of regulatory frameworks, which might be a consequence of the lack of experience of large-scale market integration of prosumers.

Norway's role as a flexibility provider in a renewable Europe

Christian Skar, Stefan Jaehnert, Asgeir Tomasgard, Kjetil Midthun, Marte Fodstad

One of the main activities in the research centre FME CenSES is scenario studies in which we analyse transition of the European energy system. This report focuses on the European power system and its transition towards 2050, whereby 90% of the emissions will be removed compared to 2010. Norwegian energy resources can potentially play a role in this transition, both in terms of flexible hydropower, natural gas, and new wind power developments. For the studies, we use the EMPIRE model developed in CenSES to handle both the long-term investment decisions and the operational uncertainty of the power system with large amounts of renewable generation from water, wind and solar PV sources. The model is tailored to determine how short-term uncertainty in inflows, load, and generation will affect the energy mix of the future in a setting in which the European countries cooperate to build a cost-efficient power system. The model has also been used to study the role of carbon capture and storage (CCS) in the European power system in cooperation with the European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP). When discussing the potential for Norwegian value creation, we include a short discussion on previous results from NTNU's and SINTEF's analyses of the value of European cooperation for short-term balancing services and point out relevant results from the HydroBalance project in FME CEDREN.

The increase of the renewable share in the European power system puts Norway in a position where it can provide flexible energy to Europe at different time horizons. Although the renewable sources in Europe will be able to replace large amounts of fossil energy, scenario studies indicate that we will see periods ranging from minutes to several weeks with large amounts of deficit energy and

similar periods with large amounts of surplus energy. Due to the variability of wind and solar power, Europe will see larger variations in power generation leading to needs for flexible alternative capacity over multiple time scales, all from minutes to hours, days, weeks, and seasons, to ensure stable and reliable power supplies.

In this report we present two different CenSES scenarios. In one scenario we assume that CCS technologies are implemented commercially, and in the other we assume CCS is not available. In both scenarios, we focus on the role of Norwegian renewable resources and natural gas in the European power mix. The power generation technology mixes in Europe in 2050 in the two CenSES scenarios are shown in Figure1a. At a European level, the analysis shows that a balanced deployment of wind and solar, along with some natural gas power production, is a cost-efficient pathway for a deep decarbonisation of European power production. When CCS is allowed, the use of natural gas is substantial, effectively doubling the share of natural gas in the mix compared to the situation without CCS, but the system is still dominated by intermittent renewable and hydropower production.

Do they work? Measures for energy efficiency with focus on buildings

Knut Holtan Sørensen

The main results presented in this report can be summarised as follows:

- Buildings have become more energy efficient over a reletively long period of time. The reasons for this are compicated and complex. Some of it is due to political measures - especially a stricter building code - some of it is due to general upgrading and refurbishment of biuldings, and some of it is due to technological development.
- Energy efficiency policy has to a large degree been dominated by a principle that this kind of investment shall be profitable or cost efficient, and by arguments for energy efficiency one-sidedly oriented towards financial gain. This line of thought has entailed a lack of understanding of the dynamcs of energy efficiency activities. A few important weaknesses: – Households build their considerations about energy efficiency measures on more complex criteria like comfort, moral and environment/climate political considerations and personal interpretations of what is profitable. – Also in the industry it is considered difficult to calculate the profitability of energy efficiency measures. Those who invest the most in this kind of measures do so because they wish to portray themselves as environment-friendly and/or because leading actors have special interests, e.g. in being environment-friendly.
- A lot of energy efficiency has happened indirectly asl a result of new technology or as a consequence of refurbishment for higher comfort.
- Stricter building codes are probably the most efficient measure, but it is limited as it primarily works with new buldings.
- There is a need for innovative thinking when it comes to measues for energy efficiency, especially as for how measures should be designed in order to address more clearly what we have called social potential for energy efficiency. Simultaneously, the report argues that it is not easy to identify alternative measures that can contribute to a stronger stimulation of energy efficiency in buildings. An obvious possibility lies in regulations for restoration. Another interesting type of measure would be to find possibilities to engage municipalities more, for instance through a support programme for "role model municipalities".

Decarbonisation of transport

Lasse Fridstrøm, Asgeir Tomasgard, Gunnar S. Eskeland, Kari Aamodt Espegren, Eva Rosenberg, Per Ivar Helgesen, Arne Lind, Marianne Ryghaug, Heidi Bull Berg, Hans Jakob Walnum, Linda Ellingsen, Ingeborg Graabak

This paper aims to provide an understanding of how electrification and hydrogen can play a role in decarbonising the Norwegian transport sector.
In 2015, the government made a commitment to link Norwegian climate policy to that of the European Union (EU). An important instrument in the EU's climate policy is the Emissions Trading Systems (EU ETS), which also covers greenhouse gas (GHG) emissions in Norway. The ambition is a 43% reduction for Europe as a whole by 2030 (compared to 2005). Electrically powered means of transport take their energy from power plants covered by the ETS and are hence included in the trading system. For emission sources outside the EU ETS, like fossil-fuelled means of transport, the national targets will be decided by negotiation, based on the respective countries' resources and capabilities. For Norway, the expectation is that the target will be a 40% reduction compared to 2005 levels. The National Transport plan towards 2029 outlines a climate strategy in the transport sector, with emissions reduced by 50% before 2030 (relative to today - amounting to 8.5 million tons CO_2 equivalents). For the transport sector, that implies reductions of 50% or more.

This report takes as a starting point that to meet Norway´s obligations, as described above, the transport sector will need a transition. Greenhouse gas emissions from transport can be cut in five different ways:

1. Reduced economic activity (GDP) and standard of living, resulting in reduced transport demand
2. Reduced mobility of people and goods at all income levels
3. Transfer of travel and freight to less carbon intensive modes
4. Improved energy efficiency of vehicles, vessels and craft
5. Transition to less carbon intensive energy carriers

We discuss these, and summarise the current knowledge regarding:

- What is the current state of policy and the observed effects on emissions?
- What are the barriers for further change?
- What is the potential for further electrification using batteries and hydrogen?
- Is a target of 50% reductions feasible within 2030, and what implications does it have for technology choice and welfare?

This paper builds on research carried out by MoZEES and CenSES research partners and summarises current knowledge on the role of electrification in the decarbonisation of the transport sector in Norway. A major benefit from this work is that it builds on and integrates insights from several disciplines—science and technology studies, economics, engineering, energy systems and markets, industrial ecology, and political science. Methods employed in the various studies are literature reviews, interviews, focus group interviews, economic analysis, various statistical analyses, energy system models and scenario development.

Other scientific results

How to facilitate cooperation in large university – industry research centres?

Collaborative efforts between researchers, industry players and regulating bodies have the potential to enhance the results from radical innovation. However, previous experience and research have uncovered that this is difficult – different intentions, timelines and culture make collaborative efforts challenging.

CenSES has researched collaboration dynamics in 15 successful innovation projects involving research partners and industry partners. Through the research, it was discovered that four elements of proximity act to mediate successful collaboration; social proximity, organisational proximity, cognitive proximity and geographical proximity. While different research partners and large research-oriented industry companies typically are close to each other in terms of organisational and cognitive proximity, more engineering-oriented industry partners would need to develop these over time. It was found that social proximity, getting to know each other personally, would be effective to mediate collaboration between researchers and engineering-oriented firms. Through socialising and interpersonal understanding, the curiosity and understanding of each others' motivations and focus can increase, at the same time increasing the cognitive proximity between the partners. The research also highlights the potential for competing industry companies to collaborate in such projects, as their employees will have a large degree of cognitive proximity.
The results from the research have been used to inform and enhance collaboration in other large research centres, such as the new FME and SFI centres, and the PhD researchers who performed this research have continued to work with other FME centres after finishing their degree.

Impact of CCS (in cooperation wit Zero-Emissions Platform)

Applying the modelling tools developed in CenSES, an assessment for the report "CCS for industry - modelling the lowest cost route to decarbonising Europe" was performed. With direct industry-related emissions accounting for a quarter of EU's total CO_2 emissions, it is clear that Europe must look beyond the power sector and likewise include core industries such as refining, steel and cement, in order to achieve the emission reduction goals. Not only is CCS the only option for substantially reducing CO_2 emissions in these industries, but the costs of CO_2 transport and storage – 10-30% of the total CCS costs – can be significantly reduced by clustering power and industrial emitters.

In order to realistically study the development of the power system, including the effect of intermittent renewable power production and deployment of storage, the long-term power system development model has the following key features:

- Incorporating both strategic expansion and operational system costs
- Maximising accuracy of RES with longer-time horizons (representative periods)
- Assessing the role and value of electricity storage combined with intermittent RES

Key conclusions of the study are:

- The absence of CCS support measures in the model not only delays CCS deployment to 2040 but leads to a CO_2 reduction of only 68% by 2050 – well below EU targets.
- Investment in CO_2 transport and storage infrastructure must start immediately in order to deploy CCS widely from 2025.
- When CCS is not part of the portfolio, the cost of reaching the EU's CO_2 reduction target for power increases by at least €1-1.2 trillion, while EU's targets for the industry are not achievable.

CENSES FINAL REPORT 2019

CenSES innovations - overview

How to develop Smart Energy Solutions?
- Recommendations for designers and implementors

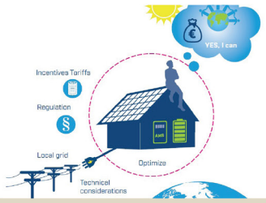
How do we integrate humanities in Horizon Europe?
- 7 advices for energy research in the new EU research agenda

How is gender dynamics affected by Smart Energy Solutions in a household?

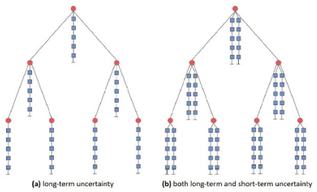
Industry and policy should go from focusing on deploying new technology, to focusing on socialization and domestication

Energy citizenship - how are our lives affected by new energy technologies?

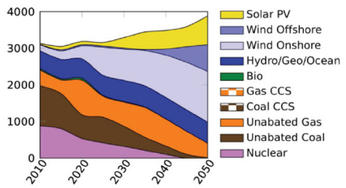
The EMPIRE-model: A new, more detailed tool for modelling the European energy system



Prosumere in Norway
- Consumers as contributors to the energy system

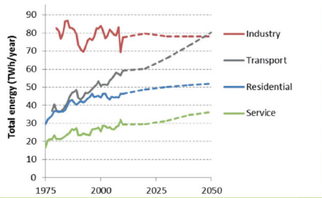


Modelling uncertainty for energy investors
- How does uncertainty affect energy investors?



What does it take for Norway to become the "green battery of Europe"?

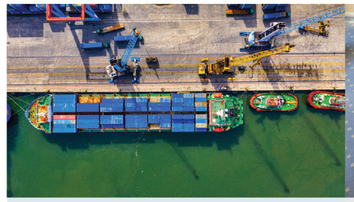
Zero Energy Buildings:
What will be the effects to the energy system from a successful Scandinavian effort?



Energy Demand in Norway towards 2050
- What affects our energy use in the future?

Norway's CO2-tax on fossil fuel cars - A success for reducing transport emissions

Direct innovation at micro level	Indirect innovation at micro level	Indirect innovation at macro level	Indirect innovation at macro level



Sulphur restrictions in shipping
- Environmental regulation can lead to higher total emissions

Cooperation in research- and innovation centres
- A guide for researchers and user partners

How do we create and stimulate new, green industries in Norway?

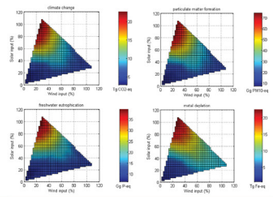
Business models for developing countries
- How to sell electricity solutions to the world's poor?

Integrating Life Cycle perspectives with IA models - Are there hidden environmental costs in the Energy Transition?

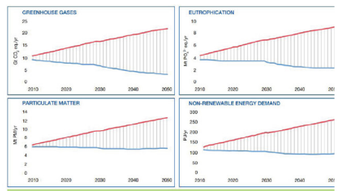
Renewable energy sources give more environmental benefits than just climate benefits

Model coupling: How does global energy development impact local energy systems?

CenSES Energy Scenarios
- How will Norway be affected by global energy policies?



Will the environmental benefit of renewables disappear with more need for energy storage and transmission?



How sustainable are renewable energies?
- Input to the UN Environment Programme

7. International cooperation

FME CenSES had a number of international collaborations. The 10 international partners listed earlier in the report in the section Facts about the Centre were at the core of this cooperation from the start of the centre, and a number of new cooperations have been initiated. In the research plans, we allocated budgets to international cooperaton in three categories:

Seed funding allocated to small focused workshops and meetings in order to create new cooperation. In some cases this would lead to new European projects, in other cases it would lead to publications.

Networking is central for building long-term collaborations, for sharing personal contacts with the rest of the centre, for dissemination and visibility in the research society, and for giving joint policy and research advise with higher impact to the centre stakeholders. We have prioritised to participate in a number of networks of this type.

New projects have been a focus area as H2020 has been strategically important for the participating inistitutions. FME CenSES and the international cooperation within the centre has positoned us well for this type of projects. In addition, we have involved CenSES international partners in projects directly financed by our user partners (like the Implications of Paris synthesis project) and other projects funded by the Research Council of Norway.

International conferences and workshops are one of the main channels both to establish and maintain cooperation and to disseminate research. It has been CenSES strategy to co-organise with other initiatives, organise events that are part of international conference or workshop series and in addtion establish the CenSES annual conference.

Exchange of researchers has been of high priority. We have facilitated a number of research visits to the centre, ranging all from a week up to a year. We have also supported our own researchers in their international research stays, promoting long-term stays. A way of structuring regular visits coud be the use of adjunct professors (20% positions). This was also used successfully in order to facilitate joint supervision, teaching and publicatons.

PhD training and education had a strong international component in CenSES. This is covered in detail in the next chapter.

Some examples: In the rest of this chapter we give examples of the networks we have participated in, some of the projects we have stablished, networking events as well as conferences, workshops and exchange. See also CenSES key figures for an overview.

International networks

EERA Joint programme E3s

The new European Energy Research Alliance (EERA) programme E3s was approved in June 2013 with NTNU and SINTEF among its founding partners. The kick-off event was held in San Sebastian in September 2013 with participants from NTNU, SINTEF and Høgskulen i Sogn og Fjordane. Other Norwegian members are IFE, Vestlandsforsking and Rokkansenteret.

The purpose of the joint program is to coordinate research within European research institutes and universities in the following subprogrammes:

- Public perception and engagement
- Analysis of policies and R&D choices
- A life-cycle approach for evaluating the sustainability performance of energy technologies
- Energy models for a system assessment of European low-carbon energy futures: markets, environmental and economic impacts
- Sustainable low carbon platform

CenSES has coordinated the subprogramme on Public Perception and Engagement (International partners in the EERA Joint programme are among others: Technalia, DTU, Austrian Institute of technology, UKERC, VTT, Aalborg University, Enea, Vito, and Karlsuhe Institute of Technology. For more information, visit www.eera-set.eu.

IEA-DSM subtask workshop

The International Energy Agency's Demand Side Management subtask visited Trondheim and CenSES in May 2013 to discuss new approaches to energy efficiency policies. Researchers from seven countries (Italy, Switzerland, New Zealand, The Netherlands, Sweden, Norway and the UK) presented case studies from various energy efficiency projects, and they discussed methodologies for evaluating policies and programmes.

Henrik Karlstrøm, the subtask national expert for Norway, presented a more in-depth analysis of the Norwegian energy story in general, as well as cases ranging from the exceptionally successful electric vehicle adoption policies of Norway to specific building retrofit projects that incorporate inhabitant participation in the decision-making process.

With the express purpose of moving away from simple information and price-based approaches to achieving energy efficiency goals, among the topics that were discussed was the literature on behavioural «nudging», and especially the increasing focus on using strategies from games design, so-called gamification.

ETSAP cooperation - Sustainability Performance of the Energy System

The Institute for Energy Technology is Norway´s partner in The Energy Technology Systems Analysis Programme (ETSAP), one of the longest running Technology Collaboration Programmes of the International Energy Agency (IEA). An example of the cooperation in ETSAP is joint analyses and workshops. In May 2017, IFE arranged, in collaboration with Spanish CIEMAT (a public research institute), a workshop called «Sustainability Performance of the Energy Systems». The workshop took place in Madrid with participants from 12 European research centres and universities. The workshop consisted of four sessions:

1) Assessment of the energy systems' sustainability
2) Energy Systems Modelling and Life Cycle Assessment
3) Input-Output Assessment
4) Impacts of energy policies

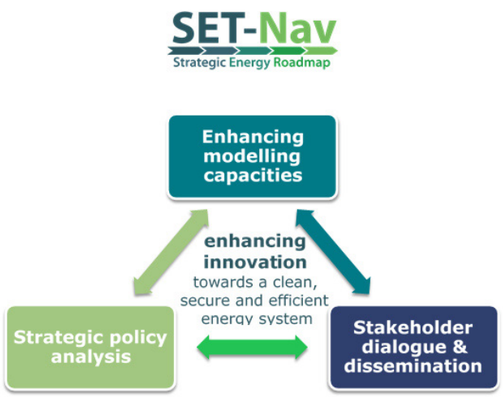
All participants presented their own research related to methods for improvements in sustainability modelling. The collaborative efforts in the workshop contributed to improved analysis of the interactions between energy systems and society, by taking into account the environment, social sciences and economics.

International Projects

SET-Nav: Navigating the Roadmap for Clean, Secure and Efficient Energy Innovation

The objective of the SET-Nav project is to support strategic decision-making in Europe's energy sector, enhancing innovation towards a clean, secure and efficient energy system. The project findings and recommendations are in line with the European Union's SET-Plan goals. The SET-Nav project rests on three pillars: modelling, policy and pathway analysis, and dissemination. To this end, SET-Nav has developed a broad and technically advanced portfolio of energy system models.

SET-Nav has implemented eleven case studies focused on the evolution of key energy sectors. For each case study, state-of-the-art modelling analyses have been performed which lead to innovative insights and sector specific recommendations. For example, findings from the case studies have provided rich information to formulate pathways that can addess the multiple dimensions of the



energy transition. This has provided a unique setting to harness multi-disciplinary understandings and to find synergetic solutions to recommend EU policies for the energy transition. The case studies have proven to be a great setting for collaboration and have produced important dissemination activities (publications, various events and presentations in Brussels and across Europe). Moreover, this has contributed to creating a web-based database to support the dissemination of results. This database will be open to the wider research community and has facilitated harmonising the data workflow among SET-Nav models.

The plan is to propose four energy transition pathways. NTNU (Pedro Crespo del Granado and Ruud Egging) is leading this endeavour. These EU pathways will inform policy dialogue and provide insights into ways to achieve decarbonisation by answering key questions, such as: how do policies (e.g. energy efficiency, carbon price, renewables support) complement each other to achieve the EU's 2030 and 2050 targets? For each pathway, what are the important elements, drivers and factors of the energy transition and their cost effective solutions? The SET-Nav pathways are inspired by the CenSES pathways generation process.

Open-Entrance

The European energy system is now entering a transition to a low-carbon future in accordance with the COP21 agreements and European Union targets and objectives set for 2020, 2030 and 2050. Energy models currently in use for the planning, support and verification of energy policies at national and European levels fail to fully encompass and integrate all the new challenges raised by the transition. Such challenges include decentralisation and variability in electricity supply, the need for flexibility, short- and long-term market dynamics, energy system integration, the deployment of innovative technologies, and the interactions between increasing numbers of independent agencies acting in liberalised markets.

The Open ENTRANCE project, started in 2019, addresses these challenges. Its aim is to develop, apply and disseminate an open, transparent and integrated modelling platform designed to assess low-carbon transition pathways in Europe. The platform will be populated with a suite of state-of-the-art modelling tools that will process data derived from the multiple dimensions of the energy transition. It will facilitate and improve dialogue between researchers, policy makers and industry during examination of the key issues linked to the transition. The project leader is SINTEF with NTNU as the largest partner. Other partners include TU Berlin, DIW Berlin, IIASA,EDF, DTU and TU Vienna.

ECHOES (Energy Choices Supporting the Energy Union and the Set-plan)

In the centre of all research activities are the technological topics of a) smart energy technology, b) electric mobility, and c) buildings. These technological aspects will have a significant impact on the economic and environmental development of the European Union.

ECHOES addresses the challenges extracted from the call by employing the innovative theoretical concept of "energy collectives" that covers determinants of energy choices from the individual level to formal social units on the societal level. Three main theoretical perspectives will be integrated into this concept, namely the perspective on (1) individual decision-making as part of collectives, (2) the perspective of collectives constituting energy cultures and life-styles, and (3) the perspective of formal social units such as municipalities, states, energy providers, or NGOs as collectives of people.

Geographical distribution of ECHOES primary data collection efforts: Countries represented in the ECHOES survey effort (blue, left), countries represented in the ECHOES psychological lab experiments (yellow, middle), and countries represented in the ECHOES focus group discussions (green, right).

Theoretical concepts

ECHOES introduces the new theoretical concepts "energy collectives" and "energy memories" that are able to combine a large spectrum of determinants of energy choices and acceptability of energy transitions and bridge the gap between different research disciplines as well as between research and policy implementation. Even though the concepts are new, they are based on established knowledge in the participating scientific fields and grounded on continuous stakeholder involvement.

SHAPE Energy and Energy-SHIFTS

First, the project SHAPE Energy established a European platform for energy-related social sciences and humanities (energy-SSH). SHAPE ENERGY aims to develop Europe's expertise in using and applying energy-SSH. The innovative platform brings together those who 'demand' energy research – including businesses, policymakers, and NGOs, who can use it to develop practical initiatives – with those who 'supply' that research.

SHAPE Energy was followed by the new project Energy-SHIFTS. This is an Energy Social sciences & Humanities Innovation Forum Targeting the SET-Plan". It will contribute to a European Energy Union which focuses on societal needs by further developing Europe's leadership in using and applying energy-related Social Sciences and Humanities (energy-SSH).

International events

Transatlantic forum in Chicago 2016

CenSES was central in organising the transatlantic forum in Chicago in 2016. CenSES researcher Tomas Moe Skjølsvold co-organised a session on smart cities, smart energy technologies and societal challenges. The session focused on how industries, cities and research can work together. It contained presentations from several sectors, authorities and researchers in Chicago (At&T University of Chicago and City of Chicago) and Norway (Lyse, Stavanger municipality, etc). The session also featured a debate where RA1 leader, Prof. Knut H. Sørensen, held a presentation on how to understand the concept «smart».

Singapore-China Energy Forum 2014

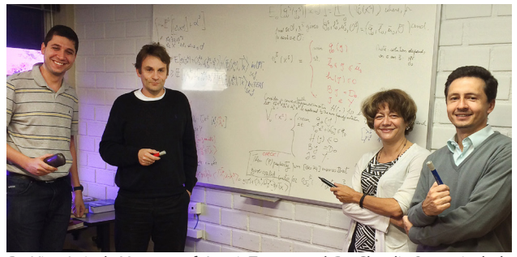
On 2 and 3 October 2014, the Energy Studies Institute at the National University of Singapore organised the Singapore-China Energy Forum 2014. The Chinese government has stated ambitions to reduce Greenhouse Gas emissions. Coal consumption must be reduced and natural gas is one option to do so. Associate professor at NTNU Ruud Egging, one of only few European participants, was invited to discuss the "Role of China in the World Gas Market". In recent years, China has started importing large volumes of natural gas. Projections by the International Energy Agency show further increasing Chinese imports, with great impact on global natural gas trade. Quantitative scenarios with the Global Gas Model, joint work by NTNU, DIW Berlin, and SINTEF Research Manager Kjetil Midthun, illustrated Chinese domestic infrastructure developments, increased liquefied natural gas imports and pipeline supplies from Central Asia and Russia. During a half-day workshop at the end of the forum, various research collaboration opportunities were discussed. There is a clear demand for Western expertise and experience in projects varying from energy market reform and carbon market design, to flexible strategic and infrastructure planning and interconnection of Chinese energy markets and transportation networks with neighbouring countries.

Prof Knut H. Sørensen held his presentation to the audience in Chicago October 24-25. Photo: Tomas Moe Skjølsvold

Exchange

Science without borders programme

Asgeir Tomasgard was given a special visitor grant under the «Science without Borders Programme» in Brazil. Since the beginning of the cooperation, he has stayed at UFSC in Florianopolis and at IMPA in Rio de Janeiro for several weeks every year. The cooperation is about developing decision support models for combined planning of hydropower and thermal resources in the Brazilian energy system. The grant was for 2014-2016, but cooperation will continue throughout CenSES lifetime and beyond with several new exchanges for PhD students from Brazil planned and the first publications appearing as this report is in print.



Dr. Vitor Luiz de Matos, prof. Asgeir Tomasgard, Dr. Claudia Sagastizabal and Prof. Erlon Cristian Finardi while modelling Hydro-thermal scheduling under uncertainty

Exchange with École Polytechnique de Montréal

PhD-student Sara Séguin from Quebec, Canada, visited CenSES from 23 March to 23 July 2015. She studies the optimal operation of hydropower dams and cooperates with the power engineering group of Rio Tinti Alca, a major aluminium producer. She studies short-term load allocation based on optimising under insecurity. Local host was Stein-Erik Fleten, Institute of Industrial Economics at NTNU.

Research exchange to TU Berlin

With support from CenSES, Øyvind Bjørgum had a research exchange stay at TU Berlin from early September to early December 2014. He was located at the Centre for Entrepreneurship under Professor Jan Kratzer. This is an international environment with high activity levels within research, education and practice-oriented programmes. Their focus is of course within the entrepreneurship domain, but they have also ongoing activities targeted towards cleantech and renewable energy, both within research and programmes. For instance, they are the German hosts of Climate-KIC, which is a large EU educational project for students and PhDs, aiming to develop innovative products that counteract the adverse effects of climate change and supporting student innovators and entrepreneurs within the field of cleantech.

Research exchange to Fraunhofer ISE in Freiburg

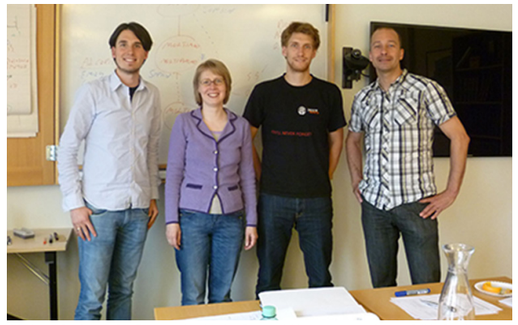
Karen Byskov Lindberg visited the Fraunhofer Institute for Solar Energy Systems (ISE) for a long-term exchange in 2014. ISE is recognised as one of the best research institutes on solar energy worldwide. The widely spread PV technology and the subsequent concept of Zero Energy Buildings is well known in Germany. Because of the experience with prosumers and smart grid technologies, this has been a focus area for research longer than in most other countries. The smart grid department at ISE covers a wide field of technologies and solutions for smart homes and smart communication technologies, which was highly relevant for Karen´s work on Zero Emission Buildings. " Working together with this team challenged my own views and ideas, and I gained significant knowledge, which resulted in a very productive year with several common papers", she comments.

Researcher exchange UCL San Diego

In the autumn of 2011, CenSES deputy director Prof. Marianne Ryghaug was invited to be part of the Science Studies research team and to collaborate with Professor Naomi Oreskes at UCL San Diego. The visiting scholar experience involved active research in the area of sustainable energy as well as participation in the activities of the Science Studies Programme. Prof. Ryghaug was placed at the University of California, San Diego, the Department of History/Science Studies Programme. She participated in a research project on Climate Change Communication which was seen as furthering the understanding of how public consensus and dissent is formed in relation to climate change both in the USA and Norway. Prof. Ryghaug gave talks in several workshops and produced publications that were widely discussed in the blogsphere (like realclimate.org).

Visiting researchers from DIW Berlin

Researchers from the DIW Berlin and NTNU have visited each other regularly during CenSES' liftetime. One example of the activities is the cooperation with Dr. Franziska Holz (now an adjunct professor at NTNU Energy Transition initiative), Daniel Huppmann and Philipp M. Richter with focus on the interaction between fossil resource markets and climate policy. A challenge in the research is modelling the resource markets. They cooperated with associate Prof. Ruud Egging, PhD student Zhonghua Su and Prof. Asgeir Tomasgard at NTNU in a project modelling the European energy markets. In addtion to the funding from CenSES and DIW Berlin, the cooperation is supported with network and exchange money from the research council and from DAAD. The main focus area of that cooperation was Multimod, the global multi-sector multi-fuel equilibrium model for energy systems studies. Multimod is a cooperation between NTNU, DIW Berlin, TU-Berlin.



Philipp Richter, Dr Franziska Holz, Daniel Huppmann from DIW Berlin and Dr Ruud Egging, NTNU. (Photo: DIW Berlin)

Steven A. Gabriel, adjunct professor from the University of Maryland

Professor Gabriel has cooperated with NTNU for the last 12 years, among others in the LinkS project in CenSES. He holds a 30% adjunct position at NTNU, focusing on research collaberation, PhD courses and supervision as well as being an international chair in the NTNU Energy Transition Initative. He is a world leading expert on energy markets and equilbrium modelling, and through his compact courses in equlibrium modelling at NTNU, he has attracted participants from all over Europe.

International conferences organised

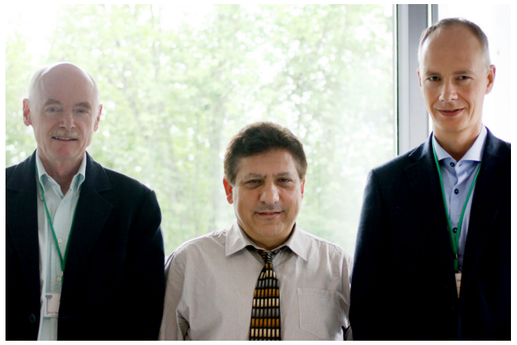
Real Options 2016

In May 2014, Scott Barrett, professor at Columbia University, gave a keynote lecture and participated in the panel debate over whether Europe can maintain its commitment to emission reductions.

The annual international conference on real options took place in Oslo and Trondheim 15-18 June 2016. This was the twentieth conference of its kind, and investments and trends related to real options were some of the topics discussed.

The conference began in Oslo on 15-16 June, while the last part took place in Trondheim on 17-18 June. The conference gathered academics and other contributors from the Netherlands, England, Spain, Austria, and many other countries. Stein-Erik Fleten, professor at NTNU and researcher within CenSES, was one of the main organisers of the conference. CenSES was one of three sponsors of Real Option 2016. The keynote speakers were Kuno Huisman and Peter Kort, both from Tilburg University.

Read more about the conference series here:
http://www.realoptions.org



The main organisers of the Real Options 2016 conference. From the left: Diderik Lund (UiO), Lenos Trigeorgis (U. Cyprus) and Stein-Erik Fleten (NTNU). Photo: Stine Mari Skeide

BEEER Conference

Bergen Economics of Energy, Environment and Research Conference (BEEER) was organised 7 times during CenSES' lifetime with CenSES as cooperation partners and Gunnar Eskeland at NHH as the main organiser. The conference has an environmental objective, emphasising to allow for young and not so young researchers to meet, get acquainted, and give each other support and resistance. The format is that young PhD students get senior researchers as discussants and vice versa.

The informal setting is partly emphasised through a panel discussion on a topic with applied appeal, over tapas and beer. An example of a topic: "Will Europe maintain its commitment in climate policy?"

The conference was supported over the years by among others CenSES, BKK, NHH, NAEE and IAEE. The two latter contributed to prizes for best master thesis.
A new BEEER conference is scheduled to take place in 2020.

NESS 2015 – Contested Natures – new strategies, ideas and dialogues?

The Nordic Environmental Social Science Conference 2015 was arranged in Trondheim as a collaboration between the NTNU and the Centre for Rural Research.

As climate change, commodification of natural resources, land deprivation, biodiversity loss, pollution and other issues pertaining to nature and natural resources are making themselves felt and seen in our daily lives, the purpose of this conference was to come together and find new ways to deal with environmental challenges and changes that are yet to come.
The conference welcomed researchers from all social sciences, humanities and other relevant fields to present their latest research related to aspects and interactions of social, cultural, and environmental changes.

Espen Moe introducing one of the key notes, Marina Fischer-Kowalski

The conference was considered a huge success with more sessions proposed than the conference could take, and over 200 researchers from a great number of nations taking part. All in all, 15 working groups were organised covering topics from "Sustainable transitions: policy and practice», Sustainable consumption, practices and devices», «Emergent technologies – Innovation in renewable energy» to «Energy Systems and Markets», all of whom were led by CenSES researchers.

Key note speakers were: Mike Hulme, on "Climate Change: One, or Many?", Marina Fischer-Kowalski on "The Anthropocene: humans lock-in with fossil fuels, and their lock-out", Katrina M Brown on "Taking animal-human (co)agency seriously in nature-society conflicts" and Paul Robbins on "Producing Wildlife: Labour and Nature in the Indian Anthropocene".

Implications of Paris

CenSES partner Joint Global Change Research Institute has invited both CenSES and CREE to join an international project called Implications of Paris. The goal of this project is to identify the most important research challenges in the wake of the Paris agreement and to inform politicians and stakeholders of potential gaps in knowledge and research.

The project consists of three sequential workshops. The first was in Maryland (2016). In March 2017, the second workshop was arranged by CenSES and CREE and took place in Trondheim. In October 2017, the third workshop was held in Tokyo, where CenSES participated.

http://www.globalchange.umd.edu/implications-of-paris-project/

From the Implications of paris meeting in Trondheim, March 2017. Photo: Solveig Avelsgård Lien

CENSES FINAL REPORT 2019

8. Training of researchers

With 45 PhD students and 19 post docs, the CenSES PhD network has been an important and integrated part of the centre. In addition, we had more than 300 master students writing their thesis on the centre topics. The percentage of international PhD students and post docs was 41% in CenSES. It was a wish from our side to have a balance both in terms of male/female and Norwegian/international students. All positions were announced through the usual channels, recruitment web sites, newspapers, the centre webpage. In addition, we used our national and international professional networks and mailing lists. A substantial part of the students were recruited thorugh these networks. In any case, we were in a situation where we could always achieve the balance mentioned above by choosing the best candidates. We found that being part of a centre and a common multidisciplinary effort made the centre an attractive place to take a PhD education.

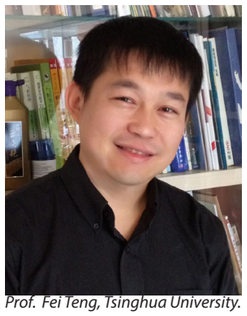
In this chapter, we will list some of the main researcher training activities included in the CenSES PhD network. In many cases, both master students, post docs and other researchers attended the activities listed below:

- Courses in writing, both scientific and popular dissemination of results
- Joint PhD seminars
- A biennial PhD school in planning under uncertainty
- A biennial PhD workshop in planning under uncertainty
- A series of summer schools in social sciences and humanities in the energy transition
- The Norren summer school series (jointly with other FMEs)
- Compact courses on specific topics (for example equlibrium modelling in economics and energy)

Some of these courses and activities are multidisciplinary and act as meeting places across disciplines, others are highly focused on more narrow topics.

Summer school in Beijing

Researcher Marius Korsnes is active in SINopse (Sino-Norwegian Partnership on Sustainable Energy). In 2017, he was one of the organisers of a summer school in Beijing: Sustainable Energy in Cities. One of the topics was the design of the olympic village for the Winter Olympics in Beijing 2022. While in Beijing, Korsnes discussed future projects with Dr. Chengwei Wang (Institute of Science, Technology and Society, Tsinghua University), Assistant Professor Yixin Dai (School of Public Policy and Management of Tsinghua University) and Fei Teng, Associate Professor (Institute of Energy, Environment and Economy, Tsinghua University). Fei Teng is now a partner in a new project partly financed by NTNU Energy, and has participated in the LinkS project in RA5.



Prof. Fei Teng, Tsinghua University.

Early Career Research School

In February 2017, CenSES researchers Marianne Ryghaug, Tomas Moe Skjølsvold and Marius Korsnes arranged an "Early career research school" at the Norwegian University Centre in Paris. NUCP is a French-Norwegian centre for the humanities and social sciences. Jonathan Rutherford, a prominent city and energy researcher from Ecole des Ponts ParisTech was keynote speaker.

Paris, February 2017. Photo: Marianne Ryghaug.

Winter school: Planning under uncertainty

Every second year from 2011 on, CenSES has organised an international PhD school in optimisation and economics. The main topic has been how to manage uncertainty in energy markets and systems, focusing both on theory and applications. Some years, other related topics such as transport, finance and logistics have been included as well. Some years, the school was co-funded by the national research school in business economics and administration.

The concept was to organise the school from Sunday evening to Saturday morning with 6 hours of lectures every day and some time for skiing and other networking in the middle of the day. The programme included lectures from 15-20 professors and 60-70 students. In the off-years, every second year, a workshop was organised with some of the same professors and students, where the students presented their own work. Usually 30-40 researchers attended these.

The main benefit from the schools, in addition to world leading lectures, has been the networks built between the students and also with the professors, many of them staying the whole week and many of them attending several times.

Most times, also some of the user partners and industrial collaborators from abroad have participated., among others from EDF in France. A total of over 400 PhD students from more than 40 universities and 25 countries have attended.

Below, we list some of the events and co-organisers from international partners. The Norwegian organisers for the whole series were Tomasgard and Fleten (NTNU), Bjørndal and Wallace (NHH).

- 2011 Oppdal, Norway
- 2013 Tignes, France, with Abdel Lisser, Paris Sud
- 2014 Bad Hofgastein, Austria, with Georg Pflug, University of Vienna
- 2015 Kvitfjell, Norway
- 2017 Passo del Tonale, Italy, with Francesca Maggioni, University of Bergamo
- 2019 Kvitfjell, Norway

In the off-years the workshops were organised in Oppdal and Geilo. The main benefit of this approach was that students got world leading professors as teachers early in their PhD education, and the year after they got the opportunity to present in front of the same professors.

From the school in Tignes, France. Top left: Sandrine Charousset; EDF, top right: Mette Bjørndal, NHH, bottom left: Shmuel Oren, UC Berkeley, bottom right: participants at the PhD winter school. (Photos: Asgeir Tomasgard)

PhD students attending summer school in Shanghai

Cooperation with Shanghai Jiao Tong

As part of the Joint Research Centre between NTNU and Shanghai Jiao Tong University, CenSES arranged a summer school for PhD students in Shanghai in June 2013. The objective for the course was to develop an understanding of social, economic and environmental aspects of energy generation and consumption in China. Ten Norwegian students participated along with Chinese students and professors from Jiao Tong.

NorRen Summer School

The Norwegian Research School in Renewable Energy has been organised most years since 2012. Normally, this is a cooperation between the University of Oslo and NTNU with participation of several FME´s. CenSES joined from the beginning and has participated by organisation and/or lectures every year. The purpose of NorRen is to give students from a broad range of disciplines a multidisciplinary overview of important topics releated to a PhD in renewable energy. Students participate in the schools along with international and national academics and experts from civil societies in lectures, field trips and debates.

A few examples:

The 2012 NorRen school in Asker was organised by NTNU and UiO with CenSES as one of the main organisers. Focus was on Implementation of Renewable Energy Technologies: Barriers and Opportunities.

The 2015 NorRen Summer School offered insights into ways to analyse the ongoing transformation of energy systems, with a focus on the example of the German Energiewende. This school had lecturers from NTNU but was organised by the University of Oslo jointly with the Environmental Policy Research Centre (FFU) at the Freie Universität Berlin. One of many highlights was the visit to the coal mine Geisendorf where participants could observe how coal is produced, and how this affects the environment.

The 2016 NorRen Summer School was held in Sogndal, Norway from 8–13 August. The participants and lecturers came from a wide range of disciplines and nationalities to explore Norway's renewable energy landscape, which was illustrated beautifully by the high mountains and deep fjords of Sogn and Fjordane County. This was organised by UiO and CensES.

Trans-Atlantic Consortium on Energy Markets Modelling (TACEMM)

This is an INTART project funded by the Norwegian Research Council to support excellent research and education through international networks. TACEMM is related to Research area 2: Energy Systems and Markets, and 3: Economic Analysis. The network addresses the transition to a sustainable energy system and how the main drivers will affect its design and operation. Today's market designs and corresponding planning and scheduling tools are not adequate to manage the complex future energy system currently under development. The focus areas of TACEMM are 1) Models, theory and studies that look at the design and operation of modern energy systems. 2) Theory and analysis that supports markets that will ensure efficient resource utilisation, a fair welfare distribution, and incentives to invest in new capacity. TACEMM plays an important role in increasing our capability to integrate new research knowledge into master and PHD level courses.
Project partners:

- Norwegian University of Science and Technology (NTNU)
- Norwegian school of economics (NHH)
- University of Maryland (UMD), USA
- Technische Universität Berlin (TUB), Germany
- Universidade Federal de Santa Catarina (UFSC), Brazil
- Universidade Federal do Rio de Janeiro (UFRJ), Brazil
- State University of Campinas (UNICAMP), Brazil
- Instituto Nacional de Matemática Pura e Aplicada (IMPA), Brazil
- Johns Hopkins University (JHU), USA.

The first PhD courses were held in November 2018 with professors Ben Hobbs, Mette Bjørndal and Endre Bjørndal teaching energy markets. The first PhD/industry days arranged by TACEMM were held in Paris in January 2019 with participation of among others EDF and Equinor as well as researchers from France, Norway, Brazil and the USA. TACEMM sponsored the 2019 PhD winter school in March in Kvitfjell.

Study trip to Renewable Land

PhD students in social sciences conduct research on how the development and use of renewable energy influences society and vice versa.

In May 2013, CenSES organised a PhD School in Sogn og Fjordane, where students had the possibility to study this from a closer perspective.

Around 20 bachelor students and 20 researchers participated in the tour organised by staff at Vestlandsforsking, Høgskulen i Sogn og Fjordane and Kunnskapsparken.

The weeklong trip had two purposes. Firstly, visits to hydropower plants and dams gave the students the possibility to see in practice how most of the Norwegian power is produced and its flexibility.

Secondly, the visits to companies, research centres and government offices were a great opportunity to get first-hand information about possibilities and challenges for environmentally friendly energy in a region rich in resources.

Among the stops during the week were:

- Statkraft: Jostedalen hydropower plant
- HiSF: Sogndal campus
- Sogn og Fjordane fylkeskommune
- Kaupanger Energy (small hydropower)
- Statnett: Fardal - Ørskog grid development
- Cool Flame Technologies (fuel cell start-up Høyanger)
- Sparebanken Sogn og Fjordane
- Sogn og Fjordane energi
- Vestavindkraft (wind power development, Sandane)
- Fjordvarme (district heating, Nordfjordeid)
- Mehuken wind farm
- Easy form (manufacturing, Måløy)
- Stadt Towing Tank.

Jostedalen hydropower plant. Photo: Asgeir Tomasgard

Two former PhD-students on their motivation and the advantages on being connected to CenSES

Håkon Endresen Normann: My motivation for starting as a PhD at CenSES

Håkon Endresen Normann, UiO.

An important motivation for me to start at CenSES as a PhD student was that the programme gave me the possibility to combine my academic background from innovation studies with my interest in climate and restructuring issues. CenSES had identified tasks that linked innovation, politics and restructuring, which gave me a platform for doing research on a theme that was (and is) both important and academically relevant. Another significant point was there was room fo me, within the areas defined in the centre, to develop my own PhD project. Hence, I was free to follow the ideas that I myself, together with my supervisors, found the most interesting.

I found the work with the PhD project itself at times to be somewhat detached from CenSES main areas. I think this was due to the fact that I was employed by the University of Oslo, whereas the bulk of the research activities for the rest of the centre was happening in Trondheim. The academic heterogeneity in the centre at times also made it somewhat challenging to see the links with some of the other academic sections beyond the thematic community. However, the huge advantage of being connected to CenSES was that it contributed lagely to the development of my own network. I got acquainted with researchers I later on had the opportunity of working with on publications, applications, workshops and dissemination. This has been pivotal for my professional development and for my further academic career.

I am now employed as a post doc at the TIK Centre for Technology, Innovation and Culture where I have the possibility to build further on the work I did during my PhD. CenSES has helped strengthening the TIK Centre's research on restructuring, and several large projects have been started at TIK which overlap with the work I did as part of CenSES. As a post doc, it has been a great experience to be part of the academic community at TIK. The plan ahead is to continue research on restructuring and innovation whithin the field of climate and energy, gladly in collaboration with researchers I have known through CenSES.

Karen Byskov Lindeberg: The advantages of being a PhD-student at CenSES

Karen Byskov Lindeberg

I started with a public PhD in 2011 associated to NVE. Through my PhD I have been associated with both FME CenSES and FME ZEN. Being affiliated to a research center has been of great importance for the development of my work on the doctoral dissertation. First, you get to know a large network of both professor and other doctoral students. Having the opportunity to discuss research questions and refine the assignment with others, in addition to the main supervisor, has been a great advantage. In addition, it is nice to get to know a large group of other PhD-students, something that provides improved learning processes and social relationships.

CenSES has also been very good at arranging writing courses and other courses for PhD-students, with both academic and social benefits. The CenSES' annual conference has been a usefull arena for meeting up with the partners of the center, and a place where you can discuss results and new ideas. In these ways it was very useful for me to be a part of the centre.

After completing my degree, I continued to work in the Energy Department at NVE in the same position I had when I started my PhD. Two years ago, I was hired as Associate Professor (20% position) at the Department of Electrical Engineering at NTNU where I teach and supervise master- and PhD-students. And just over a year ago, I changed job from NVE to SINTEF Community where I work with energy-flexible buildings. Both in my work at NVE, NTNU and SINTEF, I have had direct use of the work that I did in the PhD, and I still use it as a basis for what I am working on today: energy-flexible low-emission buildings and how these affect the energy systems around us.

PhD candidates employment after CenSES

PhD-cadidates have reported to be working for the following employers after finishing their degrees:

Centre user partners	Other companies	Public organisations	University	University outside Norway	Norwegian research institute	Research institute outside Norway	Labour organisations	Unknown	total
2	5	2	25	1	2	3	2	3	45

Their employers are:

- Powel
- SINTEF
- Gjensidige
- Steem 1960
- Statkraft
- Pöyry Norway AS
- Asplan Viak
- Ministry of Education and Research
- Sogn og Fjordane County Council
- NTNU
- Western Norway University of Applied Sciences
- OsloMet
- NHH
- UiO
- BI
- Aarhus University
- NOFIMA
- Western Norway Research Institute
- ESRI Economic & Social Research Institute, Ireland
- List Luxemburg
- VATT Institute for Economic Research
- NITO
- Samfunnsviterne

9. Communication/Popular dissemination of knowledge

CenSES communication and dissemination external stakeholders and target groups

We defined the main target groups for the research in CenSES to be:

- Goverment at local, national and EU-level.
- Government agencies
- Businesses and industry
- Youths in education
- Other FMEs
- The research council

The basis for our communication strategy has been to:

- communicate directly to these
- participate in public discussion, debates and in news media
- participate in seminars, conferences and other events where these are present

In addition, we have used some specific measures to reach the target groups like:

- the CenSES webpage,
- a newsletter series
- a podcast series
- short policy briefs
- 2-page descriptions of main research findings
- position papers from user cases

CenSES annual conferences

Every year in December, we have organised the CenSES annual conference with presentations from researchers, user partners and invited guests. From the start, this has been an excellent arena both to present the main CenSES results, train young researchers in a friendly environment and invite user partners to dialogue on important topics. Usually, these conferences have had around 70-90 participants.

The last annual conference took place in November 2018 with an international profile and more invited guests. It was organised as a dissemination conference focusing on CenSES main results and panels around this with 170 participants. That was followed by a research day with three parallel sessions.

All presentations from the CenSES annual conferences can be found on www.censes.no as well as those from the final event on https://www.ntnu.no/censes-konferanse.

Participants networking at CenSES annual conference. (Photo: Claude R. Olsen)

CenSES Energy and Climate Conference 2018

CenSES final conference was organised at Holmenkollen Park Hotel over two days in November 2018. The first day had around 180 participants and both industry, academia and government contributed in panels and with presentations.The second day gathered 70 researchers discussing the same topics in depth:

Future Energy Systems: An emission-free energy system in 2050 is the ambition of Europe. In order to reach this goal, a high degree of renewable energy is essential. Active consumers, integration between energy markets and flexibility in the production of energy in Europe are key components in this transition. This track focused on the interplay between technology, system, market and individuals.

Well Below 2 Degrees: To what extent are Norway and the rest of the world on their way changing the direction necessary to meet the commonly shared goal of well below 2°C? This track discussed discrepancies between ambitions and action. Different perspectives, measures and means to reduce greenhouse gases in both Norway and the world in general were presented.

Socio-technical energy transitions: As energy and transport systems across the world are expected to change in a more sustainable direction, society is also being transformed. Thus, the politics of energy transitions are also related to culture, practices, innovation and everyday life. It is therefore important to explore how diverse actor collectives participate in the transition, how unexpected realms of life are affected by transition activities, as well as which new opportunities these dynamics create for commercial activity and business.

Speakers and panel discussions at CenSES final conference in 2018.

Sveinung Rotevatn *KLD* | Anne Vera Skrivarhaug *NVE* | Marius Holm *Zero* | Aud Tennøy *TØI* | Jan Fuglestvedt *CICERO* | Andrea Dahl Viggen *Trønderenergi* | Arild Hermstad *MDG* | Thor Erik Grammeltvedt *Statnett*

Frances Eaton *Nysnø Klimainvesteringer* | Jan Fredrik Stadaas *Equinor* | Anniken Auke Borgen *Trønderenergi* | Gunnar Eskeland *NHH* | Marianne Ryghaug *NTNU* | Christian Klöckner *NTNU* | Pernille Seljom *IFE* | Asgeir Tomasgard *NTNU*

Marianne Ryghaug (left) deputy chairman in CenSES together with Jonas Gahr Støre (Leader of the Labour party), and Ylva Lindberg.

The Lerchendal Conference 2015

The Lerchendal Conference 2015 was in Trondheim and gathered 240 politicians, business leaders, and academics under the theme of "Change Agents for Green Growth". The purpose of this conference was to engage and discuss the fact that climate change, destruction of biodiversity and globalisation confronts us with a number of major societal challenges. Marianne Ryghaug, deputy chairman of CenSES, participated in the conversation about "Green growth in Norway" along with Vidar Helgesen (EU / EEA minister), Jonas Gahr Støre (the Labour party leader), Måns Nilsson (Deputy Director & Research Director, Stockholm Environmental Institute), Bjorn K. Haugland, Chief Sustainability Officer, DNV GL and Unni Steinsmo, President, SINTEF.

Among many highlights were Gahr Støre's speech about EV policy. Gahr Støre emphasised that: "The vision of a zero emission transport sector within 15-20 years is realistic". Ryghaug highlighted the link between research and the green shift. She said that research may provide new creative technology solutions in the future, and she pointed out that if we are to achieve a successful integration of smart energy technologies and more distributed energy solutions, we need active consumers who engage in technology. Ryghaug also argued that it will be interesting to see which technologies have the potential to create engagement and commitment among the consumers, as engagement is needed to create a green shift.

Smartgrid presentation to the Norwegian Ministry of Petroleum and Energy

In 2016, CenSES, represented by deputy director Marianne Ryghaug and Tomas Moe Skjølsvold, was invited by the Ministry of Petroleum and Energy to present social scientific research from two ERA-net projects on smart grids. The presentation highlighted the need to understand the social and cultural dynamics of innovation in the smart grid field, as well as the importance of understanding the dynamics of everyday life and the role that electricity plays there, in order to be able to design successful technologies and market mechanisms for ordinary households. The presentation concluded with concrete advice for designers, policy makers and funders of research.

Tomas Moe Skjølsvold, NTNU (KULT) Photo: NTNU

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Grønn Agenda

On 25 February 2014, the Ministry of Climate and Environment invited to a debate at NTNU. CenSES Director Asgeir Tomasgard participated in the panel together with the Minister of Climate and Environment Tine Sundtoft. The Grønn Agenda (Green Agenda) meeting was the third in Sundtoft's tour around the country in order to get input to the initiative for green development and environmental technology.

"We are facing a huge challenge. We must transform production and consumption as to achieve about 80 percent lower greenhouse gas emissions and much better resource efficiency. This means large investments each single year for 30 to 50 years. Hence, the demand for technologies which can help tackle this challenge", Sundtoft said.

Sundtoft is keen to see climate and environmental challenges as something which creates new opportunities for society. Sundtoft was more specific on what green development is about: development of environmentally friendly input factors in a number of industries, for everything from renewable energy to maritime transport, construction and processing industries and utilisation of natural resources such as seaweed and kelp for production of food and energy. All panel participants agreed that focusing on environmental technology needs governmental support.

"For many investments in environmental technology, the risk is too high as long as pollution is cheap. Often, this is immature technology which is to be rolled out in immature markets. In such cases, the government should purposely subsidise investments at an early stage", Asgeir Tomasgard stated.

Tomasgard also had specific suggestions to overcome this: "In order to increase commercialisation of research, direct measures such as earmarked supplementary scholarships for interested PhD candidates are conceivable. This way, they can learn more about entrepreneurship already during their training period".

For more information about the panel discussion, see www.censes.no.

The Ministry of Climate and Environment invited to debate at NTNU.

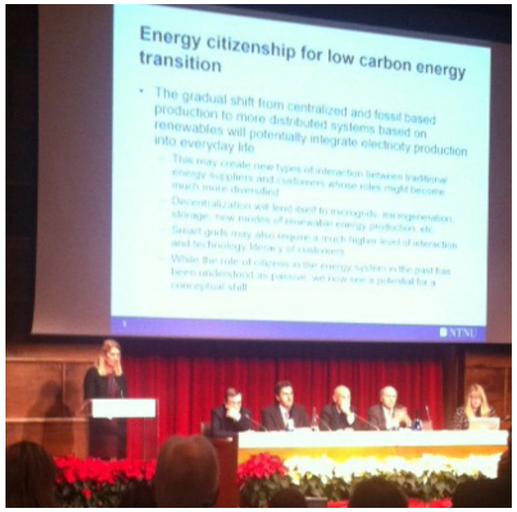
Driving the Energy Transition Together: Research & Innovation for the Energy Union

On "Energy Citizenship" Professor Marianne Ryghaug, Deputy Director of CenSES, attended the SET-Plan conference in Rome from 9-11 December 2014 as a key note speaker.

The 2014 SET- Plan Conference fell at a crucial time, when momentum was gathering towards the development of the SET Plan Integrated Roadmap and an Action Plan promoting stronger collaboration between Member States and with the EU in areas such as energy efficiency, competitive low-carbon supply of energy, and system optimisation including smart cities and communities.

Gathering 500 energy stakeholders from across Europe, the SET Plan conference facilitated debate around the EU's key energy policy targets for 2030: sustainability, competitiveness and security of supply, and the importance of research and innovation in achieving them. After an overall political introduction about the Integrated Roadmap, Session 2 provided an overview of the needs and expectations for the European energy system of key European stakeholders: Industry, research, civil society and private investors.

Ryghaug presented the citizens' perspective. In her speech, she covered the needs of civil society towards a low-carbon energy system for Europe; the main expectations of the area with respect to the development of a low carbon energy system and the specific research and/or innovation challenges the community is facing to contribute to a competitive, sustainable and secure energy system. The presentation focused on the role of citizens and contribution of social sciences and humanities in the development of a low-carbon energy system for Europe, important factors that may trigger the engagement of citizens towards new low carbon energy technologies; and the main elements for an active participation of citizens in the energy system and related policy making.



Marianne Ryghaug, key note speaker at SET-Plan

Ryghaug argued that policy makers expect and need people to become more active participants in energy systems in order to reach ambitious climate goals: "While citizens in the past have been understood as passive, we now see a potential for a conceptual shift where we will have to think differently about how to engage users and communities towards new low-carbon energy technologies". Ryghaug claimed knowledge about energy citizenship to be vital for the success of the SET plan.

CenSES Centre Director is a member of the Climate Council

CenSES director, Prof. Asgeir Tomasgard, has since 2014 been a member of the Advisory Board of the Minister of Climate and Environment's climate council, the so-called "Klimarådet". The main role of this advisory board is to give input on the transition to a low emission society by 2050. The board consists of participants from business and industry, labour organisations, NGOs and academia. Tomasgard presents insights from CenSES research on topics like the climate law, national transport plan, green growth, climate policy and climate negotiations.

Norway´s role discussed at Technoport forum

As the first version of the position paper *Norway´s role as a flexibility provider to a Renewable Europe* was finished on 13 June 2013, CenSES in cooperation with CEDREN and Technoport, arranged the first Technoport forum. This forum is a meeting place for top-management from industry, government and education meant to promote dialogue on topics of strategic importance for Norway.

The day started out with a presentation from European Commissioner for Climate Action Connie Hedegaard participating at the ISES (International Student Energy Summit) in Trondheim, followed by a Technoport talks session with 6 presentations:

- The Norwegian Minister of Petroleum and Energy, Ola Borten Moe
- Asgeir Tomasgard (CenSES) – The future European power system under different climate policies
- Atle Harby (Cedren) – Hydropower for energy storage and balancing
- Jonas Egerer (DIW Berlin) – The European energy system
- Karl Johnny Hersvik (Equinor) – Natural Gas, a key in Europe's energy future
- Rune Volla (Research Council) – Norwegian energy research.

The session was rounded off with a conversation between Ola Borten Moe, Connie Hedegaard and Asgeir Tomasgard.

After the presentations, the forum met in an informal panel debate at Lerkendal Gård addressing the topics presented during the day. There were participants from Statkraft, Statnett, NTNU, SINTEF, NHH, Equinor and Enova.

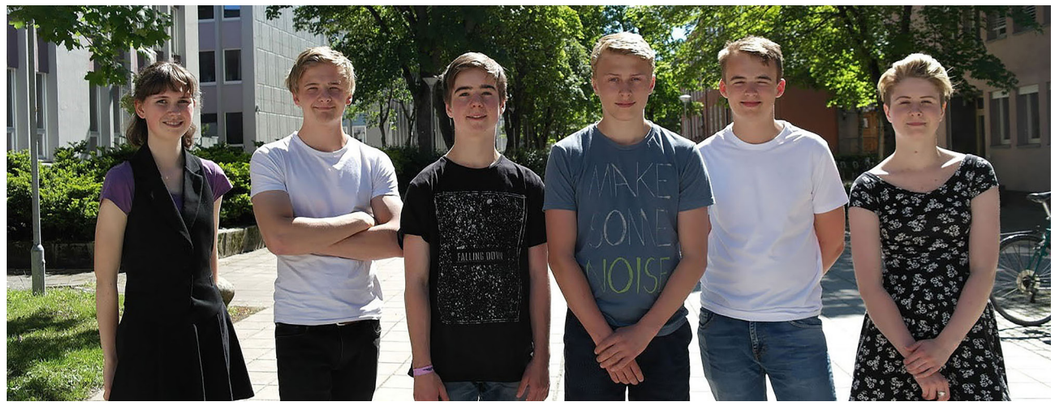
For more information visit www.technoport.no/talks.

Photo 1: Connie Hedegaard, European Commissioner for Climate Action, Ola Borten Moe,who was then Norwegian Minister of Petroleum and Energy and Asgeir Tomasgard, director CenSES.
Photo 2: Johan Einar Hustad, then Pro-rektor innovasjon, Arne Bredesen, strategisk satsings-område NTNU, and Nils Kristian Nakstad, adm.dir. Enova.

CenSES final seminar, May 2019

In May 2019 CenSES arranged a final seminar where we thanked the management team and the board for the work with the centre through its eight years. All the different partners who had been involved with the centre were present, in addition to The Norwegian Research Council and Pro-Rectors for Research at NTNU and NHH, Bjarne Foss and Kenneth Fjell.

Parts of the Board and management grupp of CenSES. Board Charman Johan Einar Hustad, Lasse Torgersen, Hanne Wigum, Mette Bjørndal, Frode Rømo, centre director Asgeir Tomasgard and deputy director of CenSES Marianne Rygghaug. Matthias Hoffman, Arne Lind, Ola Lingaas, Fulvio Castellacci and Petter Hersleth from the Board was not present. Photo: Hilde Wormdahl



From left: Martine Klock Fleten, Sondre Duna Lundemo, Thor Ivar Helgesen, Sigve Lysne, Markus Valås Hagen, Marianne B. Eid.
Photo: Kristine Klock Fleten.

UngEnergi

Ung Energi

Ung Energi is a group of students who seek to improve secondary school students' understanding and interest in renewable energy. FME CenSES established Ung Energi in 2012. Our main goal is to encourage teachers to include information about renewable energy in their lessons. In the summer of 2017, Ung Energi hired five new employees to create new content for the website, and revise the old. Ung Energi has since produced texts about nuclear power, innovative energy solutions, international climate agreements and much more.

This past year we have experienced an increase in the number of visitors to our website ungenergi.no. In the autumn of 2016, our monthly average of visitors was around 6000, while in autumn 2017 it was around 11 000. This is, of course, a development we are very happy with, and it is great to see that we reach more and more people.

Our statistics show that our most popular text of autumn 2017 was the one on hydrogen-powered cars, which is also interesting to note. Although most of our articles and other projects are written and developed during the summer, we have also finished some articles and projects in the autumn: an article about "the future of airplanes", as well as one about Klimasøksmål Arktis, just to mention a few.

We have also developed a teaching programme about hydropower for high school students. In addition to the teaching programme itself, we have made a video explaining how to construct a hydropower plant. Finally, we have worked for a long time with a project regarding the life cycle of a mobile phone, named UselTSmartly. This project has been further developed, with the addition of a website, as well as more texts and exercises.

Ung Energi presenting at CenSES final seminar.
Photo: Hilde Wormdahl

NTNU Energy Transition Initiative

In 2016, NTNU and Equinor initiated a new research initative on Energy Transition Strategies. It is our ambition to recruit international experts on the topics and strengthen cooperation with leading research groups. So far, Equinor and NTNU have financed the new programme, each with 5 million NOK yearly over 8 years. The results from FME CenSES are the main reason why this initiative was started, with Equinor providing their funding as a gift to strengthen research on energy transtion.

CenSES has been a co-organiser of all the events in the Energy Transition weeks. In March 2017, the programme organised its first Energy Transition conference in Trondheim with more than 400 participants, and around 1200 following the live stream. In 2018, we organised an Energy transition week with several events and a conference with 600 paritcpants. In 2019, the number had grown to 800 participants in the conference, and 7 workshop on the remaining days.

The purpose of the Energy Transition week is to establish a dialogue between academia, policy makers, business and industry, focusing on the major challenges in the transition.

The initiative's partners are TU Berlin, DIW Berlin, University of Maryland, MIT, Joint Global Change Research Institute, NREL, Oxford University, Cambridge University, IIASA, RWTH Aachen and more.

For more information see:
https://www.ntnu.edu/web/energytransition and
https://www.ntnu.edu/energytransition-conference

Twitter @FMECenSES

In August 2019, CenSES had 900 followers, an increase of 167 followers since 2018. We were following 2051, all key national and international stakeholders such as industry, decision makers, politicians, scientists, researchers and NGOs. We use twitter to present our research and to communicate with people who are sharing the same passion about sustainable energy.
The Twitteraccount will change name to @FME_NTRANS if possible.

Top: Energy Transition Conference 2017. Bottom left: Panel participants in the 2018 conference. Bottom right: Minister of oil and energy Terje Søviknes in the 2017 keynote. Photos: Ole Martin Wold.

10. Effects of the centre for the company partners and public partners

Enova, by Per Ivar Helgesen

CenSES has provided availability to the knowledge frontier in disciplines that are relevant to us. The centre has strengthened the knowledge base for us as a user partner.

CenSES has taken initiatives to define user cases, and has been responsive and willing to work on issues/user cases that are relevant to the user partners.

By arranging relevant events, the centre has disseminated new knowledge and also improved the access to competent personnel and research institutions. Such events have served as constructive arenas where fruitful discussions on current issues have taken place.

Deliveries such as a common projection on future energy demand have been valuable input to our internal processes. Such deliverables, reports and position papers have much greater value to us when they come from a research centre based on discussions from multiple agents, than when they come from consultants.

Equinor, by Hanne Wigum

What we believe has been an essential part of the CenSES collaboration is that the centre has been able to produce a lot of interdisciplinary work. The centre has assembled academic disciplines that traditionally did not work together to look at complex issues. It has been important and very successful.

What we have used directly from the work in CenSES is the energy system analyses. This has been a tool in our annual updates on energy perspectives, which is our scenario-based approach. There has been a lot of dialogue between those who are responsible at Equinor and the research institutions.

Something else that has been useful to us is the analysis of what the future energy mix will look like. When making decisions that affect the development of the energy systems in the future, it is important to have a good factual basis. This is not an exact science, there are many ways and directions this can take, but at least we can agree on a framework in which we have a similar opinion on the preconditions for the different scenarios. The different models with and without CCS, to see what role gas can play in the future of Europe, has for instance been useful to us and fits into the strategic issues that we are facing.

Therefore, we have appreciated that CenSES has worked with specific user cases and real analyses that we can use directly.

BKK, by Toril Hunstad Christensen

There are such huge changes taking place right now, so that the development of the brand and regulatory changes are difficult to keep up with. In addition, changes happen very quickly and a change in the wrong direction can quickly turn out very wrong. Therefore, it has become all the more important to research the consequences of the changes in a socio-economic perspective with both sustainability and cost / benefit as a starting point, and what energy policy will be right to support a market-focused development!

As a user partner, this is what we take with us from CenSES:

- Strengthened network with other industry players and academic institutions
- Strengthened knowledge base for our own analyses and assessments
- It has become very clear to us as business users that consumer behaviour and expectations of energy citizenship are increasingly important research area.
- For BKK, it is very important to focus on the need for flexibility in the future power system and the role of hydropower'as it was done in CenSES towards the end of periods.
- Political risk and the importance of climate risk has increased considerably during the CenSES period and has been put on the agenda by the CenSES research.

Hydro, by Lasse Torgersen

What has been most valuable to us by participating as a user partner in CenSES is the networking we have gained through the centre. One example is that we have visited connections in Beijing several times whom we have become acquainted with through CenSES.

When it comes to applied research from the centre, we have not actively used it that much. But that is due to the fact that research takes time, while we operate in a market that is constantly changing, so we need to make faster changes than what research often can contribute to. That said, we still believe that the models and theories that have been developed through the research, are very valuable.

It all builds on a totality, a total understanding of the energy system, and this is where the research contributes in an important way. It is also important for us that the centre contributes to the education and development of people who will have an expertise in the energy field in Norway. It is essential that we build up expertise and understanding of the energy systems. Therefore, it is vital that Hydro, as a major social player, participates.

Research must be independent, but it should at the same time be in coexistence with society. User partners like us can contribute to get even more relevance into the research, by suggesting user cases and the likes. Therefore, we have made ourselves available for anyone who wants to talk to us or ask us questions related to the energy industry.

11. Future prospects

The research groups in FME CenSES will continue their cooperation in the newly funded FME NTRANS-Norwegian centre for Energy Transition Strategies. For more see the next page.

NTNU Energy Transition Initiative

Another spin-off from CenSES is the NTNU Energy Transition Initiative. In 2016, NTNU and Equinor initiated a new research programme on Energy Transition Strategies. It is their ambition to recruit international experts on the topics and strengthen cooperation with leading research groups. So far, Equinor and NTNU have financed the new programme with 40 million NOK each over 8 years. In October 2016, a start-up workshop, "Energy Transition 2016", was organised in Trondheim to yield ideas for the shaping of the programme. Leading experts from DIW Berlin, TU Berlin, IIASA, MIT, University of Maryland, Joint Global Change Research Institute, University College Dublin, Imperial College, Oxford University and Cambridge University participated. A number of CenSES user partners were also present, among others Equinor, Statnett, Statkraft and Enova. Topics identified so far are: energy and climate policy towards 2050, the role of integration of natural gas, heat and electricity, the role of natural gas towards 2050, megatrends and disruptive changes: new business models in the energy sector, the role of demand side management, energy storage and transmission in interplay with renewables. In 2018, Statkraft joined the initiative.

From the left: Eldar Sætre (Equinor) and Gunnar Bovim (NTNU) wish to build a world-leading research group to develop sustainable energy solutions. Photo: NTNU/ Thor Nielsen

CenSES and NTRANS - a platform for cooperation with technology FMEs

Over the lifetime of CenSES, we have had excellent cooperation with technology FMEs on position papers, joint seminars and new projects. During the last three years, CenSES has established cooperation with most of the new technology FMEs established in 2016. This cooperation was established through CenSES researchers participating in the new FME consortia. Likewise, the research design of the new FME NTRANS has prioritised cooperation with some of the same technology FMEs. Cooperation has been at the core of CenSES and through this new cooperation and joint user cases with technology FMEs, it will also be central for FME NTRANS.

Over 50 participants from government, industry and public offices were invited to the workshop that was held at Rådssalen, NTNU on October 20-21 2016. Photo: Stine Mari Skeide

FME NTRANS - Norwegian Centre for Energy Transition Strategies

While CenSES initially focused on the transition of the energy system, we realised more and more over the years that the main challenge will be the transition of society to a sustainable and low-emission future, in which the energy system will play a key role. The new centre FME NTRANS will focus on this transition of society and the links between humans and technology, between the energy system and the rest of the economy in sectors like industry, transport and the built environment. Fundamental drivers are digitalisation, the focus on sustainability, and the wish for continued welfare and value creation from Norwegian energy resources.

The process around NTRANS started already in October 2017, when CenSES organised a round-table conference with researchers and representatives from the industry and public administration in order to create a good dialogue around central research challenges at the interface between social sciences and technology. Both CenSES partners and others were invited. The backdrop for such a conference was that CenSES, together with its partners, has conducted research for about ten years, and in the period between 2008 and 2018 has educated 64 PhDs and postdocs in the centre, in addition to the affilliated connected projects.

This roundtable-conference for CenSES and its partners was organised to develop the strategy for the next ten-year period, and input from industry and public administration was of great value when identifying the most important fields for the social science research within energy and climate for the ten years to come.

Snapshot from round-table conference. Photo: Solveig Lien.

This turned out to be a success, and in the autumn of 2019, the new centre is planned to start with around 30 user partners, 10 international partners and a budget of around 300 million NOK for the 8-year period.

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Appendix 1: Finances

Funding table	2011		2012		2013		2014		2015		2016		2017		2018		2019		All years		
Partner	financial	inkind	financial	inkind	financial	inkind	financial	inkind	financial	inkind	financial	inkind	financial	inkind	financial	inkind	financial	inkind	financial	inkind	total
NTNU IØT	0	4 015	0	6 236	0	6 391	0	5 315	0	4 348	0	3 759	0	3 927	0	2 679	0	442	0	37 112	37 112
NTNU HF	0	3 670	0	3 951	0	4 246	0	4 601	0	3 018	0	3 819	0	3 865	0	6 222	0	3 139	0	36 532	36 532
NTNU Indecol	0	0	0	616	0	616	0	674	0	609	0	121	0	57	0	68	0	-175	0	2 585	2 585
NTNU Elkraft	0	0	0	0	0	22	0	32	0	87	0	42	0	0	0	0	0	0	0	183	183
NTNU Samfunnsforskning	0	0	0	0	0	18	0	12	0	0	0	0	0	0	0	0	0	0	0	30	30
UiO	0	990	0	3 414	0	2 776	0	2 542	0	2 190	0	1 989	0	1 133	0	3 086	0	444	0	18 564	18 564
HiSF	0	613	0	1 166	0	866	0	952	0	6 536	0	3 593	0	7 142	0	3 083	0	1 448	0	25 399	25 399
VF	0	392	0	477	0	797	0	684	0	0	0	0	0	0	0	0	0	0	0	2 350	2 350
NHH	0	1 650	0	1 912	0	1 750	0	1 800	0	1 850	0	1 900	0	1 950	0	1 875	0	0	0	14 687	14 687
Sintef EF	0	2 179	0	2 362	0	2 039	0	2 166	0	2 049	0	1 612	0	1 606	0	1 638	0	0	0	15 651	15 651
Sintef TS	0	964	0	1 265	0	1 277	0	1 219	0	1 384	0	1 060	0	231	0	263	0	0	0	7 662	7 662
IFE	0	700	0	700	0	700	0	700	0	700	0	701	0	701	0	1 471	0	0	0	6 374	6 374
SNF	0	500	0	500	0	500	0	500	0	500	0	500	0	500	0	701	0	0	0	4 201	4 201
Total research partners	0	15 673	0	22 599	0	21 998	0	21 198	0	23 271	0	19 097	0	21 111	0	21 086	0	5 298	0	171 329	171 329
Total user partners	3 900	947	4 025	1 127	2 317	1 006	3 202	1 276	4 832	765	5 020	744	4 100	936	2 450	883	-270	0	29 575	7 685	37 260
Research Council	4 235	0	9 866	0	12 273	0	9 730	0	11 409	0	9 295	0	5 870	0	8 396	0	8 927	0	80 000	0	80 000
Total	8 135	16 619	13 891	23 726	14 590	23 004	12 931	22 474	16 241	24 036	14 315	19 841	9 970	22 047	10 846	21 969	8 657	5 298	109 575	179 014	288 589

Cost per research area	2011		2012		2013		2014		2015		2016		2017		2018		2019		All years		
	financial	inkind	financial	inkind	financial	inkind	financial	inkind	financial	inkind	financial	inkind	financial	inkind	financial	inkind	financial	inkind	financial	inkind	total
BUDGET RA1	506	3 977	1 149	4 953	597	4 740	558	5 151	811	3 113	1 479	4 358	1 275	3 362	2 098	5 466	3 282	3 036	11 756	38 155	49 911
BUDGET RA2	2 699	5 036	3 465	5 286	3 137	5 205	2 333	4 009	2 131	2 458	2 352	1 100	1 034	1 791	2 184	1 805	529	48	19 864	26 738	46 601
BUDGET RA3	1 612	2 586	2 282	2 851	2 093	2 651	2 731	2 778	2 983	2 721	2 309	2 879	1 873	2 684	1 070	2 796	376	0	17 330	21 946	39 276
BUDGET RA4	1 634	2 207	3 590	6 466	3 345	6 800	3 952	6 086	4 630	10 558	2 316	5 666	1 882	9 738	1 216	7 992	281	1 943	22 844	57 456	80 300
BUDGET RA5	364	1 050	1 052	1 888	2 093	1 622	2 050	2 091	2 443	2 650	2 127	3 432	1 710	2 371	514	1 846	576	-128	12 930	16 823	29 752
BUDGET Management	785	1 764	1 542	2 256	1 046	1 928	1 312	1 861	1 095	2 513	1 071	2 406	609	2 101	1 227	2 062	611	399	9 297	17 291	26 588
BUDGET Center	535	0	811	26	1 772	58	652	498	2 147	23	2 241	0	1 588	0	2 538	0	3 271	0	15 555	605	16 160
TOTAL	8 135	16 619	13 891	23 726	14 083	23 004	13 588	22 474	16 241	24 036	13 895	19 841	9 970	22 047	10 846	21 969	8 927	5 298	109 575	179 014	288 589

Cost per partner	2011		2012		2013		2014		2015		2016		2017		2018		2019		All years
Partner	financial	inkind	financial	inkind	financial	inkind	financial	inkind	financial	inkind	financial	inkind	financial	inkind	financial	inkind	financial	inkind	
NTNU IØT	127	4 015	813	6 236	1 806	6 391	1 176	5 315	1 192	4 348	1 302	3 759	1 071	3 927	290	2 679	614	442	45 501
NTNU HF	992	3 670	2 469	3 951	2 620	4 222	2 125	4 601	2 563	3 011	3 486	3 819	2 004	3 865	3 562	6 222	6 244	3 139	62 565
NTNU Indecol	0	0	0	616	880	616	1 487	674	1 467	609	890	121	616	57	63	68	0	-175	7 988
NTNU Elkraft	96	0	247	0	216	22	289	32	263	87	53	42	0	0	0	0	0	0	1 347
NTNU Samfunnsforskning	0	0	0	0	58	18	0	12	40	0	0	0	82	0	0	0	0	0	210
UiO	84	990	726	3 414	1 351	2 776	1 113	2 542	896	2 190	334	1 989	829	1 133	800	3 086	773	444	25 469
HiSF	1 181	613	1 730	1 166	986	866	1 242	952	2 114	6 536	1 348	3 593	695	7 142	857	3 083	0	1 448	35 551
VF	650	392	650	477	0	797	510	684	510	0	510	0	510	0	455	0	0	0	6 145
NHH	699	1 650	1 176	1 912	938	1 750	938	1 800	1 579	1 850	937	1 900	886	1 950	248	1 875	0	0	22 089
Sintef EF	999	2 179	2 494	2 362	1 472	2 039	1 040	2 166	860	2 049	1 458	1 612	1 042	1 606	1 376	1 638	185	0	26 577
Sintef TS	840	964	1 168	1 265	1 104	1 277	1 014	1 219	1 910	1 384	1 015	1 060	577	231	1 504	263	-112	0	16 683
IFE	1 400	700	1 347	700	1 332	700	1 410	700	1 569	700	1 329	701	848	701	1 000	1 471	795	0	17 404
SNF	907	500	898	500	789	500	1 051	500	789	500	949	500	700	500	564	701	376	0	11 224
Total research partners	7 975	15 673	13 718	22 599	13 551	21 974	13 397	21 198	15 751	23 264	13 611	19 097	9 859	21 111	10 721	21 086	8 875	5 298	278 755
Total user partners	0	947	0	1 127	0	1 006	0	1 276	0	765	0	744	0	936	0	883	0	0	7 685
Abroad	160	0	173	0	532	24	192	0	490	7	284	0	111	0	125	0	52	0	2 149
Total	8 135	16 619	13 891	23 726	14 083	23 004	13 588	22 474	16 241	24 036	13 895	19 841	9 970	22 047	10 846	21 969	8 927	5 298	288 589

Appendix 2: Related Projects Including CenSES Research Partners 2011 - 2019

1 Modelling and forecasting risk in the electricity market, car bon market and related energy markets (ELCARBONRISK).
RCN/RENERGI. 2010 - 2014.
Project leader: Sjur Westgaard, NTNU.
Total budget: NOK 13 770 000

2 Investment in renewable electricity under climate policy un certainty (PURELEC).
RCN/RENERGI. 2010 - 2014
Project leader: Stein-Erik Fleten, NTNU.
Total budget: NOK 8 450 000

3 Congestion Management and Block Bids in Deregulated Electricity Market.
RCN/RENERGI. 2009 - 2012
Project leader: Kurt Jörnsten, NHH.

4 Public acceptance of post carbon strategies
RCN/RENERGI. 2009 - 2014
Project leader: Knut Holtan Sørensen, NTNU.
Total budget: NOK 8 891 000

5 Building markets, shaping policy? The role of economics in energy policy and energy use.
RCN /RENERGI. 2007 - 2013
Project leader: Knut Holtan Sørensen, NTNU.
Total budget: NOK 3 368 00

6 Renewable strategies? Implementing and commercializing new energy technologies.
RCN/RENERGI. 2008 - 2012
Project leader: Knut Holtan Sørensen, NTNU.
Total budget: NOK 5 048 000

7 ECar, A strategy for electrification of road transport in Nor way.
RCN /RENERGI. 2009 - 2013
Project leader: Tarjei Solvang, SINTEF Energy Research.
Total budget: NOK 10 600 000

8 Environmental Sustainability Benchmarking of Low-Carbon Energy Technologies.
RCN/RENERGI. 2011 - 2013
Project leader: Edgar Hertwich, NTNU.
Total budget: NOK 2 954 000

9 Optimal power network design and operation.
RCN /RENERGI. 2011 - 2015
Project leader: Morten Hovd, NTNU.
In budget for CenSES: NOK 2 700 000

10 Guidelines for the implementation of "Electric Road Trans port" policies in Europe.
ERA-NET and RCN /RENERGI. 2010 - 2012
Project leader: Marianne Ryghaug, NTNU.
Total budget: NOK 315 000

11 Dissemination of Scientific Knowledge as a Policy Instru ment in Climate Policy. RCN/NORKLIMA. 2011 - 2014
Project leader: Göran Sundqvist, UiO.
Total budget: NOK 6 200 000

12 Intermittent Renewables, Balancing Power and Electricity Market Design (INTREPED).
RCN/RENERGI. 2012 - 2015
Project leader: Gunnar Eskeland, SNF.
Total budget: NOK 6 000 000.

13 Regional effects of energy policy (RegPol).
RCN /RENERGI. 2012 - 2015
Project leader: Arne Stokka, SINTEF Technology and Society.
Total budget: NOK 11 950 000

14 Financial Engineering Analysis of Investment and Opera tions in Electricity Markets (FINERGY).
RCN /RENERGI. 2007 - 2012
Project leader: Stein-Erik Fleten, NTNU.
Total budget: NOK 8 099 061

15 Renewable energy as transition strategy.
RCN/RENERGI. 2011 - 2014
Project leader: Keith Smith, UiO.

16 The future Norwegian energy system in a European context
RCN/RENERGI. 2011 - 2014
Project leader: Kari Aamodt Espegren, IFE.
Total budget: NOK 7 270 000

17 Nordic Energy Technology Perspectives
Nordic Energy Research. 2011 - 2012
Project leader: Kari Aamodt Espegren, IFE.
Total budget: DKK 833 000

18 Professionalism and pragmatism? The management of env ironmental knowledge and interdisciplinarity in consulting companies.
RCS/Miljø2015. 2008 - 2012
Project leader: Vivian Anette Lagesen, NTNU.
Total budget: NOK 5 994 000

19 Energy Technology System Analysis Programme
RCN/RENERGI. 2012 - 2015
Project leader: Kari Aamodt Espegren, IFE.
Total budget: NOK 1 720 000

20 Integrating households in the smart grid (IHSMAG).
ERA-NET. 2012 - 2014
Project leader NTNU: Marianne Ryghaug, NTNU.
Total budget: EUR 1 148 810

21 NORSTRAT - Nordic electricity road map 2050: Strategic choices towards carbon neutrality
Nordic Energy Research. 2011 - 2015
Project leader: Ingeborg Graabak, SINTEF Energy Research
Total budget: 14 384 156

22 NORD-STAR - Centre of Excellence for Strategic Adaptation Research.
Nordforsk. 2011 - 2015
Centre director: Michael Goodside, Aarhus University.
Total budget: NOK 35 000 000

23 Teknologibasert entreprenørskap og innovasjon som driver for industriell utvikling i Nord-Norge.
NFR og Helgeland Sparebank. 2013-2016.
Project leader: Roger Sørheim, NTNU/Handelshøgskolen i Bodø.
Total budget: NOK 5 500 000

24 uselTsmartly - Environmental peer-to-peer education for youths with focus on smart use of Information and Commu nication Technologies.
IEE, 2013 - 2016
Project leaders: Knut H. Sørensen and Robert Næss, NTNU.
Total budget: NOK 2 300 000

25 Greenhouse gas emission goal for cars; feasibility and policy instruments.
SD, 2012 - 2013.
Project leader NHH: Gunnar Eskeland.
Total budget: NOK 500 000

26 Crafting Climate Advisors - Developing Arenas for the Edu cation of Craftsmen in the Face of Climate Transitions
KLIMAFORSK. 2013
Project leader: Jøran Solli, NTNU
Total budget: NOK 187 000

27 Influence of bioethanol fuels treatment for operational per formance, ecological properties and GHG emissions of spark ignition engine
EEA. 2013-2015
Project leader: Otto Andersen, Vestlandsforsking

28 Hvordan vil en dreining av fornybarstøtten i EU i retning av mer markedsstyrte instrumenter påvirke grønne investorer? (RISKY-RES)
NFR, ENOVA, NVE, Statnett og Energi Norge. 2013-2016.
Project leader: Stein-Erik Fleten, NTNU.
Total budget: NOK 7 000 000.

29 Bringing environmental knowledge into action: Environ mental
knowledge management in Norwegian local governments.
Miljø2015 program. 2014 - 2017
Project leader: Vivian Anette Lagesen, NTNU.
Total budget: NOK 5 000 000

30 Europeanisation of energy-technological innovation sys tems: drivers,
consequences and strategic challenges for Norway.
ENERGIX. 2014 - 2017
Project leader: Per-Ove Eikeland, Fridtjof Nansens Institutt.

31 Renewable Energy Projects: Local Impacts and Sustainabili ty (RELEASE)
NFR 2014-2017
Project leader: Erling Holden
Total budget: NOK 25 000 000

32 Day-Ahead Bidding with Multiple Short-Term Markets.
Sintef Energy Research 2015-2018
Project leader: Marte Fodstad
Total budget: NOK 18 000 000

33 Integration of Power Transmission Grids - Prospects and Challenges at National and European Levels in advancing the energy transition.
ENERGIX/NFR 2014 -
Project leader: Andersen, Allan Dahl

34 Preliminary project support for network building and re search application.
Innovasjon Norge Sogn og Fjordane 2014-2015
Project leader: Carlo Aall

35 Hybrid and other configurations for environmentally friend ly transport
MARINTEK. (2014 – 2015)
Project leader: Elizabeth Lindstad
Total budget: NOK 2 550 000

36 Norwegian Energy Road Map 2050.
SINTEF Energy Research.
Project leader: Marte Fodstad
Project startup: 2016
Total budget: NOK 14 900 000

37 Navigating the Roadmap for Clean, Secure and Efficient En ergy Innovation – SET-Nav (Horizon 2020)
TU Wien, NTNU and SINTEF Technology & Society with partners
Project leader: Gustav Resch,
Local project leaders: Ruud Egging (NTNU), Kjetil Midthun (SINTEF)
Project startup: 1. April 2016 - 31. March 2019
Total budget: EUR 3 999 411,25

38 Internationalization of Norwegian Offshore Wind Capabili ties (InNOWiC)
EnergiX. 2016 - 2020.
Project leader: Asbjørn Karlsen
Total budget: NOK 10 800 000

39 Project title: Markets - actors - technologies: A comparative analysis of smart grid solutions
Funding source: ERA-net Smartgrid plus
Year: 2015-2017
Project leader: Toke H. Christensen, Aalborg universitet
Total budget: NTNU: 5,3 mill NOK, whole consortium 14, 1 mill Nok

40 Framtidsbilder: Det norske lavutslippssamfunnet
Vestlandsforsking
Employer: ENOVA
Project leader: Carlo Aall, Vestlandsforsking

41 SHAPE-ENERGY.
Coordinated by: Anglia Ruskin University.
Partner: NTNU (KULT).
Project leader from NTNU: Sara Heidenreich, KULT

42 INVADE.
Coordinated by: Smart Innovasjon Østfold.
Project partner: NTNU (KULT)

43 ECHOES
Financed by H2020
Project partner: NTNU

44 MATCH
Financed by Smartgrids ERA-net
Project partner: NTNU

45 Greening the Fleet – Sustainability Transitions in the Maritime Shipping Sector (GREENFLEET)
Project leader: Tone Merethe Aasen (tone.m.aasen@sintef.no)
Programme: EnergiX, Norges Forskningsråd 2017-2020
Budget: 11,8 mill NOK

46 Scenarios for the Norwegian Low Emission Society post-2050. Three different (Nor)ways to reach a low emission so ciety in 2050 and beyond
NTNU, 2016
Employer: ENOVA
Project leader: Knut H. Sørensen (NTNU)
Budget: NOK 176 000

47 Where Does the Green Economy Grow? The Geography of Nordic Sustainability Transitions (GONST)
Project leader: Teis Hansen, Lund University. Leader WP5 (Policy Learning): Håkon Finne (hakon.finne@sintef.no)
Programme: Nordic Green Growth Research and Innova tion Programme, Nordic Innovation, NordForsk and Nordic Energy Research, 2017-2020
Budget: 20 mill NOK

48 Conditions for growth in renewable energy industries (Re newGrowth). EnergiX project.
Project leader: Jens Hanson, TIK, UiO.
Partners: Utrecht University & SINTEF TS.
Budget: 10,3 M NOK.

49 Trans-atlantic cooperation on energy market models (TA CEEM). INTPART.
Project leader: Asgeir Tomasgard, Department of Industrial Economics and Technology Management, NTNU.
Partners: Norwegian University of Science and Technology (NTNU), Norwegian school of economics (NHH), University of Maryland (UMD), Technische Universität Berlin (TUB), Universidade Federal de Santa Catarina (UFSC), Universi dade Federal do Rio de Janeiro (UFRJ), State University of Campinas (UNICAMP), Instituto Nacional de Matemática Pura e Aplicada (IMPA), Johns Hopkins University (JHU).
Budget: 6.350.000.

50 Transition towards zero emission ports (TRAZEPO). EnergiX project.
Project leader: Nokut, SNTEF TS.
Partners: Narvik Havn, Kristiansand Havn, Oslo Havn, KS Bedrift Havn, Kystverket, Norske havner.
Budget: 10,5 mill.

51 Where does the green economy grow? (GONST). The geog raphy of Nordic sustainability transitions.
Project leader: Markus Steen.
Project management: Lund University, Department of Ge ography.
Funded by Nordfors, Nordic Energy Research and Nordic In novation over the Nordic Green Growth Research and Inno vation programme.
Budget: 20 M NOK.

52 Assessment of the value of flexibility of the Norwegian Ener gy Resources (ASSETS).
Project leader: Pernille Seljom, IFE.
Partners: NTNU-IØT, SINTEF TS.
Budget: ca 10 M NOK.

53 Integrated Transport and Energy Modelling (ITEM).
Project leader: Kari Espegren.
Partner: TØI.
Budget: 8,8 M NOK.

54 Sirkulært Trøndelag (STRØ). Preliminary study. Programme: Forkommune.
Project leader: Mats Mathisen Aarlott.
Partners: SINTEF TS & Trøndelag Fylkeskommune.
Budget: 300 000 NOK.

55 DRIVERS (Transport 2025)
Project leader: Tomas Moe Skjølsvold (NTNU)
Period: 2018 - 2022
Partners: NAF, NLF, Statens Vegvesen, Kolombus, NITO, AtB, Forus Næringspark, Stavanger kommune, Kjeldsberg
Budget: 8 mill

56 Energy-Shifts (H2020)
Project leader: Marianne Ryghaug (NTNU). ARU (UK) coordi nating
Period: 2019-2021
Budget: 1 mill EURO

57 Biobatt (Nano2021) Bio-degradable Li-ion Battery Anodes
Project leader: Anne Marie Svensson (NTNU), Marianne Ryghaug (KULT)
Budget: KULT 2 mill

58 OpenENTRANCE (H2020)
Project leader: Ingeborg Grabak (Project coordinator, SINTEF Energy) and Asgeir Tomasgard, Pedro Crespo del Granado (WP lead, NTNU)
Budget: 5 mill Euro
Period: 2019-2023

59 BEYOND: Blockchain based electricity trading on integrating local and national electricity markets
Project leader: Pedro Crespo del Granado (Project coordina tor/lead, NTNU)
Budget: 2 mill Euro
Period: 2019 - 2022

60 Syn.ika: Sustainable plus energy neighbourhoods
Project leader: Niki Gaitani (Project coordinator, FME CenSES, NTNU) and Pedro Crespo del Granado (NTNU Tasks lead)
Budget: 7.5 mill Euro
Period: 2019-2023

61 Smart Cities and sustainable urban ecosystems (+Cityx Change), H2020
Project leader: NTNU as the Project coordinator, and Pedro Crespo del Granado /Asgeir Tomasgard as NTNU Tasks lead
Budget: 30 mill Euro
Period: 2018-2023

62 HONOR HOlistic flexibility market iNtegration Of cRoss sec toral energy sources
Project leader: TU Dormunt (project lead), Hossein Farah mad (WP lead, NTNU) and Pedro Crespo del Granado (Task contributor, NTNU)
Budget: 3.1 mill Euro
Period: 2019-2022

Contact persons for the research partners

Norwegian University of Science and Technology (NTNU)

Department of Industrial Economics and Technology Management (IØT)
Roger Sørheim
Email: roger.sorheim@iot.ntnu.no

Department of Interdisciplinary Studies of Culture (KULT)
Tomas Skjølsvold
Email: tomas.skjølsvold@ntnu.no

Department of Energy and Process Engineering
Anders Hammer Strømman
Email: anders.hammer.stromman@ntnu.no

SINTEF Energy Research
Stefan Jaehnert
Email: Stefan.jaehnert@sintef.no

SINTEF AS
Frode Rømo
Email: Frode.romo@sintef.no

Institute for Energy Technology (IFE)
Kari Aamodt Espegren
Email: kari.espegren@ife.no

Norwegian School of Economics (NHH)
Gunnar Eskeland
Email: gunnar.eskeland@nhh.no

Institute for Research in Economics and Business Administration (SNF)
Ivar Gaasland
Email: ivar.gaasland@snf.no

University of Oslo, Centre for Technology, Innovation and Culture (TIK)
Olav Wicken
Email: olav.wicken@tik.uio.no

Høgskulen på Vestlandet
Erling Holden
Email: erling.holden@hisf.no

Vestlandsforsking
Hans Jakob Walnum
Email: hjw@vestforsk.no

"Knowledge and engagement for sustainable energy transition"

Centre for Sustainable Energy Studies

CenSES - Centre for Sustainable Energy Studies
Faculty of Humanities
NTNU
NO-7491 Trondheim
Norway

www.censes.no

Contact persons for the centre management:

Asgeir Tomasgard, Director
asgeir.tomasgard@iot.ntnu.no

Marianne Ryghaug, Deputy Director
marianne.ryghaug@ntnu.no