CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

Oslo Centre for Research on Environmentally friendly Energy

Final Report 2011-2019

1. Foreword

This is the final report of CREE —The Oslo Centre for Research on Environmentally friendly Energy. CREE was established by the Norwegian Research Council in 2011 as one of three social science research centres on environmentally friendly energy (FME-S). The Frisch Centre has served as the host institution of CREE, with the Research department at Statistics Norway; Department of Economics, University of Oslo; and Tilburg Sustainability Centre as the main research partners. During the operational period of CREE, which ended in December 2019, the centre had four subcontractors and nine user partners.

The main goal of CREE was to generate knowledge that can contribute to a cost-effective and sustainable exploitation of Norwegian and international energy resources on the way towards the low-emissions society, that also ensures an effective and fair climate and energy policy, both nationally and internationally. The ambition of CREE was to become a leading international research centre; to create a dynamic environment for rigorous and policy-oriented studies through interaction with user partners; and to contribute to recruitment and training at the master, doctoral and post-doctoral levels in energy and environmental economics. We believe we have succeeded.

This report contains information on the outputs from the centre: scientific papers; dissemination of knowledge to professionals, user partners and society at large; cooperation between the research partners; user-oriented activities; educational activities; and assessment of the extent to which CREE has managed to meet its own visions and to contribute to the overarching goal of the Norwegian Research Council to form a solid knowledge basis for how to attain environmental and energy policy targets.

2. Summary

Vison of centre and key research topics

Main vision: To generate knowledge that can contribute to a cost-effective and sustainable exploitation of Norwegian and international energy resources by industry and governments, as well as an effective and fair climate and energy policy, both nationally and internationally.

Key research topics:

- Radical emissions reductions in ETS sectors: Examine driving forces of emission activities in ETS sectors, and choice of regulatory instruments in ETS sectors, including carbon capture and storage (CCS).
- Environmentally friendly transport: Identify, analyze and recommend sustainable emission reduction strategies for the transport sector.
- Green innovations and utilization of smart technologies: How can policies motivate and incentivize research, development and diffusion of environmentally friendly technologies.
- Towards the low-emissions society. Study pathways for nations, regions and the world towards the low-emission society.

Research output

Publications: CREE has published 203 papers in peer reviewed international journals, see Appendix 3b. Several of the papers have been published in top field journals covering environmentally friendly energy. A few CREE papers have been published in top 5 general economics journals. In addition, CREE has published 82 papers in popular science journals, the centre has 96 other scientific publications, and 148 CREE working papers, see Appendix 3c-3e.

Awards:

During the CREE project period 2011-2019, the Erik Kempe award has been given as many as three times to CREE researchers. The prize is awarded every other year to the best paper in the field of environmental and resource economics, with at least one author affiliated to a European research institution.

The 2013 Erik Kempe Award was given to CREE researcher Bård Harstad for his study "Buy Coal! A Case for Supply-Side Environmental Policy", published in Journal of Political Economy.

The 2017 Erik Kempe Award was given to the two CREE researchers Mads Greaker and Kristoffer Midttømme for their article "Optimal Environmental Policy with Network Effects: Will Pigouvian Taxation Lead to Excess Inertia?" published in Journal of Public Economics.

The 2019 Erik Kempe Award was given to the two CREE researchers Bård Harstad and Torben K. Mideksa for their article Conservation Contracts and Political Regimes, published in Review of Economic Studies.

In 2012, CREE researcher Michael Hoel received the price for the best paper published in the Scandinavian Journal of Economics (The Supply Side of CO2 with Country Heterogeneity).

In January 2017, the Sören Wibe prize was awarded jointly to CREE researchers Michael Hoel, Bjart Holtsmark, and Katinka Holtsmark for their paper Faustmann and the Climate, published in Journal of Forest Economics. The Sören Wibe Prize is awarded biannually to an article that presents considerable development in empirical knowledge or methodology in the field of forest economics and is published in the Journal of Forest Economics.

The research group was awarded the grade "very good" by the RCN commissioned evaluation of social sciences in 2018 (SAMEVAL). In addition, the group's work for the green tax commission was highlighted as one of four good practice cases for societal impact in economics.

Snapshot of research output:

- Policy design with network goods. The Nomination Committee of the 2017 Erik Kempe Award gave the following motivation for the award: "Mads Greaker and Kristoffer Midttømme receive the Erik Kempe Award for a novel and insightful contribution to the literature on environmental tax policy, which focuses on economies with network goods. They characterize the optimal tax on an externality-generating good in this environment. They also show, by means of numerical simulations that are calibrated to the adoption of electric vehicles in Norway, that network effects may temporarily motivate much higher taxes than suggested by standard Pigouvian formulas, and that suboptimal tax policies neglecting these network effects may hinder the diffusion of clean substitutes for the dirty technology."

- International cooperation to lower GHG emissions. Free-riding is at the core on environmental problems: If a climate coalition reduces its emissions, world prices change and non-participating countries typically emit more, for example, by extracting the dirtiest type of fossil fuels. If, however, countries can trade the rights to exploit fossil-fuel deposits, the best policy of a coalition is simply to buy foreign deposits and conserve them, see Harstad (2012a), which was published in the prestigious Journal of Political Economy and was awarded the 2013 Erik Kempe Award.

- Alternative measure to cut GHG emissions. Nine CREE researchers argue in a paper published in Science that the Paris Agreement can be strengthened if complemented by a treaty among fossil fuel producers on limiting global fossil fuel supply, see Asheim et al. (2019). A supply-side climate treaty could enhance the impact of the Paris Agreement in the presence of free riders, since reduced supply will contribute to rising fossil fuel prices for all market participants. It could also stimulate investment in low-carbon technology research and development (R&D), basically through the same price increase mechanisms. Finally, with a supply-side agreement carbon policies could look more acceptable to fossil fuel producers, also as a result of the fossil fuel price impacts.

- The future price of EU carbon allowances. Aune and Golombek (2020) offers a comprehensive assessment of the approved EU 2030 climate and energy package from 2018. The authors find that the targets for renewables and improved energy efficiency have been set so high that the implied GHG emissions reduction is 50 percent, which is higher than the agreed-upon 40 percent target by the key EU institutions – the Commission, the European Parliament, and the European Council. The paper finds that by achieving the renewable and energy efficiency targets, both the ETS and non-ETS emissions targets are met. This suggests that the future ETS price will be low.

- Zero GHG emissions and storage. Gaure and Golombek (2019) show, using optimization combined with simulations of spatial, hourly, re-analysis data for the period 2006-15, that the EU can design an electricity generation sector where around 98 percent of total production is generated by wind power and solar. This requires, however, that the storage (e.g., battery) energy capacity corresponds to 4 percent of average annual consumption of electricity. If the EU allows for overcapacity in total supply of wind and solar, the storage energy capacity can be reduced. For example, if total production of wind power and solar over the period 2006-15 is at least one third larger than total load, there is no need for a backup technology, and the required storage energy capacity is much lower than 4 percent of average annual consumption of electricity.

Training of researchers

The CREE research partner, Department of Economics at the University of Oslo, organizes regular PhD and Master courses, including classes related to environmentally friendly energy; this topic is covered in courses in energy economics, electricity economics, resource economics, environmental economics and climate change economics.

CREE organized one PhD class on integrated assessment models jointly with MILEN (in 2013), the University of Oslo’s (former) interfaculty research network on environmental change and sustainable energy. CREE researchers have also given PhD or Master lectures related to environmentally friendly energy, both in Norway and abroad.

CREE has offered Master Thesis scholarships to Master students writing their Master thesis within environmentally friendly energy.

International cooperation

The international cooperation in CREE consists of four elements:

- An international research partner, Tilburg Sustainability Centre, with competence to complement CREE researchers

- International research affiliates. Each of these complemented the competence of the Norwegian CREE researchers
- All international research affiliates have always been invited to the annual CREE workshops, along with other international researchers in the field of environmentally friendly energy
- Participation in an EU funded project.

Value added to be a FME centre

The value added of being a FME centre is related to scale advantages, scope advantages, and unique funding possibilities:

- The CREE center has contributed to substantial research in the fields of energy, climate change and environmental economics, and has also trigger interdisciplinary research. While these activities can be accomplished in ordinary projects, the high number of international publications as well as the high quality of publications (most of the CREE working papers are published in top field journals or highly ranked general journals) have been possible mainly because of the long duration of the funding of CREE (Scale advantages). With CREE, researchers got the possibility to build up expertise, use their competence over several years and also to combine expertise from different fields, thereby providing a good foundation for alternative theoretical approaches, theory-based empirical work and also interdisciplinary research (Scope advantages).
- CREE has triggered substantial collaborations between the three Norwegian research partners and has also led to more contact and cooperation with the international research partner than what is possible through ordinary projects funded by the Norwegian Research Council (Scale advantages). Therefore, a substantial share of CREE publications is joint work between at least two CREE partners. Furthermore, CREE made it possible for the Norwegian research partners to build, maintain and extend domestic and international networks, which may have long-lasting effects.
- CREE has provided funding to a comprehensive extension and updating of the numerical energy market model LIBEMOD, and also made it possible to establish a new family of numerical models, suited for analysing energy and environmental policies both for the Norwegian economy and for the global economy – the SNOW models. These are now the main models for climate analyses and long-term forecasting used by the Norwegian Ministry of Finance and other ministries. It is not possible to obtain funding through ordinary projects from the Norwegian Research Council for comprehensive model development (Unique funding possibilities through CREE).
- Because of the long project period of CREE, there has been substantially more interactions with user partners than what was typical for the CREE research partners prior to CREE (Scale advantages). The dynamic environment of researchers and user partners had powerful implications with respect to generated ideas for policy questions to explore; joint research applications; and dissemination of research output. In particular, through the innovative arrangement CREE Hot Line researchers affiliated to CREE provided information on recent advances in the field of environmentally friendly energy to user partners.

Contribution for the overarching goal of the FME-programme

The overarching goal of the FME programme is to develop a scientific basis for the handling of environmental and climate challenges. CREE has covered all Norwegian energy-related GHG emissions sources, and also examined how to promote renewables. CREE has explored, within a multidisciplinary framework, costs and benefits of initiatives aiming at improving energy efficiency. CREE has contributed to design of instruments and regulations to reach energy, climate and environmental policy targets, as well as identifying obstacles on the way towards the low-emission society. The Centre has explored standard measures, like incentivised policy measures, as well as alternative measures, for example, supply-side climate policy measures.

While the main objective of CREE has been to improve the general knowledge base for policy design, CREE researchers have also contributed to reports from appointed commissions, and provided input to ministry publications, including The Green Tax Commission, Klimakur, various deliveries to Norwegian ministry publications, Norwegian expert groups and IPCC.

Norsk sammendrag

(Abstract in Norwegian)

Senterets visjon

CREE skal fremskaffe kunnskap som kan bidra til at bedrifter og myndigheter utnytter norske og internasjonale energiressurser kostnadseffektivt og bærekraftig, samt generere kunnskapsgrunnlag for en effektiv og rettferdig klima- og energipolitikk, nasjonalt og internasjonalt.

Forskningstemaer

- *Omfattende utslippsreduksjoner i ETS-sektorene*. Undersøke faktorer som leder til utslipp i ETS-sektorene, samt analysere reguleringer og virkemidler i ETS-sektoren, inkludert karbonfangst og –lagring, som kan redusere utslippene.
- *Miljøvennlig transport*. Identifisere, analysere og anbefale bærekraftige utslippsstrategier i transportsektoren.
- *Grønn innovasjon og bruk av smarte teknologier*. Hvordan kan virkemidler påvirke forskning, utvikling og spredning av miljøvennlig teknologi.
- *Mot lavutslippssamfunnet*. Studere nasjonale, regionale og globale baner mot lavutslippssamfunnet.

Forskningsproduksjon

CREE har 203 publiseringer i internasjonale tidsskrifter med referee-ordning, se appendiks 3b. Mange av arbeidene har blitt publisert i ledende spesialtidsskrifter innenfor miljøvennlig energi. Enkelte arbeider har blitt publisert i topp fem tidsskrifter med et bredt, tematisk nedslagsfelt. Videre har CREE publisert 82 arbeider i populærvitenskapelige tidsskrifter, 96 arbeider i andre tidsskrifter, samt utgitt 148 interne rapporter (CREE working papers), se appendiks 3c-3e.

Forskningspriser

I løpet av CREEs prosjektperiode (2011 til 2019) har CREE-forskere mottatt Erik Kempe prisen tre ganger; 2013, 2017 og 2019. Denne utmerkelsen deles ut annet hvert år til det beste arbeidet innenfor miljø- og ressursøkonomi med minst én forfatter knyttet til et forskningsinstitutt i Europa. Videre har en CREE-forsker mottatt prisen for det beste publiserte arbeidet i Scandinavian Journal of Economics, mens tre CREE-forskere delte Søren Wibe prisen i 2017; denne deles ut annet hvert år til et arbeid som er publisert i Journal of Forest Economics.

Eksempler på forskningsbidrag

- *Politikkdesign og nettverkseffekter*. I en del tilfeller er nytten av et gode avhengig av et nettverk. Dette er f.eks. tilfelle for elektriske biler; disse trenger ladestasjoner. CREE-forskere har utviklet teori for hvorfor og hvordan skattlegging av miljø- og klimaskadelige goder med nettverkseffekter (f.eks. bensinbiler) – eller subsidier til deres grønne alternativer (f.eks. elbiler) – burde avvike fra verdien av den direkte miljøskadelige virkningen. Forskerne viser at dersom de politiske virkemidlene ikke tar høyde for nettverkseffektene i markedet, kan vi få en altfor treg overgang til grønne alternativer som det ville ha vært samfunnsøkonomisk optimalt å ta raskt i bruk, se Greaker og Midttømme (2016).

- *Internasjonalt klimasamarbeid*. En stor utfordring med å redusere de globale klimautslippene er at tiltak i noen land øker utslippene i land uten klimapolitikk. Virkningene kan skje gjennom bl.a. priseffekter i energimarkedene. Harstad (2012a) viser at en vei ut av dette uføret er at klimakoalisjoner kjøper ikke-utvunnet fossil energi, f.eks. kullgruver, og lar være å utvinne energien.
- *Tilbudssidepolitikk*. Ni CREE-forskere har i tidsskriftet Science argumentert for at Paris-avtalen kan styrkes gjennom en avtale mellom fossilproduserende land som reduserer produksjonen av fossilbasert energi, se Asheim et al. (2019). En slik avtale vil heve prisen på energi, og dermed redusere bruken av fossilbasert energi i land som ikke har innført en streng karbonpolitikk. De samme priseffektene vil gi et økonomisk insentiv til økt FoU innenfor klimavennlig energi.

Forskningsutdanning

CREE-partner Økonomisk institutt, UiO, tilbyr PhD- og masterkurser om miljøvennlig energi; dette temaet er dekket i kurs innenfor energiøkonomi, elektrisitetsøkonomi, ressursøkonomi og miljøøkonomi. CREE organiserte et PhD kurs om modeller som knytter sammen klima og økonomiske mekanismer (integrated assessment models) i samarbeid med MILEN (i 2013). CREE-forskere har undervist PhD og masterkurser knyttet til miljøvennlig energi både i Norge og i utlandet. CREE har hatt 13 PhD studenter (7 kvinner) og en post.doc (mann). Endelig har CREE delt ut en rekke masterstipend til studenter som har skrevet masteroppgave innenfor miljøvennlig energi, se appendiks 2a.

Internasjonalt samarbeid

CREE har hatt en internasjonal forskningspartner (Tilburg Sustainability Centre) som har komplettert CREEs forskningskompetanse. En rekke internasjonale forskere har vært knyttet til senteret og CREEs årlige forsker-workshop har vært en viktig møteplass for hele forskergruppen. Endelig har CREE deltatt i ett EU-finansiert prosjekt.

Merverdi ved å være et FME-senter

- CREEs lange prosjektperiode har muliggjort å føre arbeidsnotater frem til internasjonal publisering (stordriftsfordel). Dette er den viktigste faktoren bak CREEs omfattende internasjonale publisering av høykvalitetsarbeider (En stor andel av CREEs arbeider er publisert i høyt rangerte tidsskrifter). CREE har muliggjort både spesialisert kompetanseoppbygging og samarbeid som har trukket på flere fagfelt. Dermed har det vært mulig å utvikle alternative teoretiske tilnærminger, teoribaserte empiriske arbeider og flerfaglig forskning (breddefordel).

- CREE har ledet til betydelig mer samarbeid mellom forskningspartnerne enn det som er mulig å få til gjennom ordinære prosjekter (stordriftsfordel). En stor andel av CREEs publiserte arbeider har derfor forfattere fra minst to forskningspartnere.
- CREE har muliggjort utvikling og oppdatering av den numeriske energimarkedsmodellen (LIBEMOD) og finansiert utvikling av numeriske modeller for analyse av energi- og miljøpolitikk for både Norge og verden—SNOW modellene. Disse er nå hovedverktøyet når Finansdepartementet utarbeider langsiktige klimaanalyser. All erfaring tilsier at det ikke er mulig med omfattende modellutvikling innenfor ordinære forskningsråd-prosjekter.
- Den lange senterperioden har stimulert til flere brukerorienterte aktiviteter enn det forskningspartnerne har gjennomført i ordinære forskningsråd-prosjekter. Samarbeidet med brukerne har hatt betydning for hvilke forskningsspørsmål senteret har arbeidet med, omfanget av søknader med brukerinvolvering, samt senterets forskningsformidlingsaktiviteter.

Bidrag til det overordnede målet for FME-programmet

Det overordnede målet for etableringen av FME-sentrene er å utvikle et vitenskapelig basis for å håndtere miljø- og klimautfordringene. CREE har bidratt til dette ved å adressere hvordan norske energirelaterte klimagassutslipp kan reduseres, samt designe virkemidler for å utvikle klimavennlig teknologi. CREE-forskerne har styrket den generelle kunnskapsbasen, samt deltatt i offentlige kommisjoner og utredninger, spesielt grønn skattekommisjon, Klimakur og IPCC-arbeidet.

3. Vision/goals

The CREE Strategic Plan states the following vision for the centre:

i) To become a leading international research centre within energy, environmental and resource economics.

Own assessment: CREE researchers have published extensively in field journals covering environmentally friendly energy. CREE researchers have also published in top economics journals as well as in interdisciplinary journals. The number of publications, as well as the diversity of accepted peer-reviewed papers, suggest that CREE has been at the frontier of the field. This was confirmed by the midterm evaluation committee, who stated that CREE was a leading group in Europe, probably even world wide.

ii) To generate knowledge that can contribute to a cost-effective and sustainable exploitation of Norwegian and international energy resources by industry and governments, as well as an effective and fair climate and energy policy, both nationally and internationally.

Own assessment: As stated above, CREE researchers have published extensively in leading field journals as well in general economics journals. Furthermore, CREE researchers have participated broadly in the public debate on climate and energy issues. Therefore, we believe that our scientific output and outreach activities had, and will continue to have, an influence on Norwegian energy and climate policy. Also, our participation in the public debate may have contributed to a better understanding of energy and climate issues in the general public. We believe that the novel insight achieved by our research will help industry and policy makers in making better decisions that can help us in the transformation towards a carbon-free society.

iii) Contribute to recruitment and training at the master, doctoral and post-doctoral levels in energy and environmental economics at the University of Oslo. Recruiting women to research will have a particular focus.

Own assessment: The CREE research partner, Department of Economics at the University of Oslo, organizes regular PhD and Master courses, including classes related to environmentally friendly energy. In addition, CREE researchers have organized, or contributed to, other PhD or Master classes either at the University of Oslo or abroad, see Section 9 below.
As part of the activities of the centre, we have had 13 PhD students (7 of these are women). 8 of the 13 Phd students have received their titles (4 of these are women). We expect that 4 of the remaining 5 students will defend their theses in 2020, whereas one Phd student dropped out after one year of study (He returned to consultancy). CREE had one post. doc (male).

Also, each year we have awarded about three master scholarships to students writing their master thesis within environmentally friendly energy. Each of these students (half of them are women) have been offered a designated CREE supervisor as well as office space at a CREE institution. A modified version of one master thesis got published in the Norwegian journal Samfunnsøkonomen, whereas a modified version of another master thesis got published in the international field journal Resource and Energy Economics. Both publications are joint work between the master student and the supervisor. In addition, 14 students (12 women) wrote their master thesis within environmentally friendly energy with a CREE supervisor (but did not receive a scholarship).

To sum up, we believe CREE has contributed to recruitment and training.

4. Basic facts about the Centre

Organisation

Main organisation of centre

Research Partners:

Ragnar Frisch Centre for Economic Research (http://www.frisch.uio.no/english/)
Department of Economics, University of Oslo (http://www.sv.uio.no/econ/english/)
Research Department, Statistics Norway (https://www.ssb.no/en/)
Tilburg Sustainability Centre
(https://www.tilburguniversity.edu/research/institutes-and-research-groups/tsc)

User Partner:

Energy Norway (https://www.energinorge.no/om-oss/in-english/)
Gassnova SF (http://www.gassnova.no/en)
Norwegian Environment Agency (https://tema.miljodirektoratet.no/en/)
Norwegian Ministry of Climate and Environment
(https://www.regjeringen.no/en/dep/kld/id668/#)
Norwegian Ministry of Petroleum and Energy (https://www.regjeringen.no/en/dep/oed/id750/)
Norwegian Water Resources and Energy Directorate (https://www.nve.no/english/)
Statkraft Energi AS (https://www.statkraft.com/)
Statnett SF (https://www.statnett.no/en)
Equinor (2011-2015) (https://www.equinor.com/en.html)

Subcontractors:

IFE - Institute for Energy Technology (https://ife.no/en/)
Natural Resources Law at the Faculty of Law, University of Oslo
(https://www.jus.uio.no/english/research/areas/natural-resources/)
SUM - Centre for Development and the Environment, University of Oslo
(https://www.sum.uio.no/english/)
SINTEF (2011-2014) (https://www.sintef.no/en/)

Board

Board leaders:

Lars Bergmann
July 2015- Dec. 2019


(Bilde www.hhs.se.)

Einar Hope
July 2011-June 2015


(Bilde www.nhh.no)

Board members in 2019

Ståle Aakenes (*Gassnova*)

Brita Bye *(Statistics Norway)*

Rolf Korneliussen *(Statnett)*

Karine Nyborg *(Department of Economics University of Oslo)*

Ellen Skaansar *(Norwegian Water Resources and Energy Directorate)*

Kjell Steinar Berger *(Statkraft)*

Sverre A. C. Kittelsen *(Frisch Centre)*

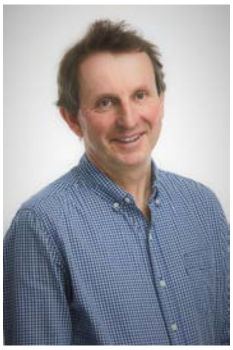
Knut Kroepelien *(Energy Norway)*

Erik Nygaard *(Norwegian Environment Agency)*

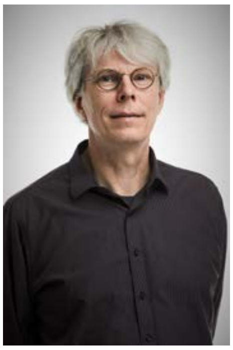
Researchers

Project leaders

Rolf Golombek
Senior
Research Fellow
The Frisch Centre
Apr. 2013-Mar. 2014
and
Oct. 2016-Mar. 2020


(Bilde www.frisch.uio.no)

Snorre Kverndokk
Senior
Research Fellow
The Frisch Centre
July 2011-Mar. 2013
and
Apr. 2014-Sep. 2016


(Bilde www.frisch.uio.no)

Key senior researchers

Brita Bye
Director of research department (acting)
Statistics Norway


(Bilde www.ssb.no)

Taran Fæhn
Head of Research

Statistics Norway


(Bilde www.ssb.no)

Mads Greaker
Professor
OsloMet


(Bilde www.oslomet.no)

Cathrine Hagem
Senior Researcher
Statistics Norway


(Bilde www.ssb.no)

Bente Halvorsen
Senior Researcher
Statistics Norway

Michael Hoel
Professor emeritus
Department of Economics


(Bilde www.uio.no)

Ole Røgeberg

Senior Research Fellow
The Frisch Centre


(Bilde www.frisch.uio.no)

Nils-Henrik M. von der Fehr
Professor
Department of Economics


(Bilde www.uio.no)

Other researchers:
See Appendix 2b

Cooperation within the centre

In CREE, research activities are organized in Flagships. In order to strengthen the cooperation between the research partners, all main research partners participate in all flagships. Hence, most projects have participation from at least two research partners, thereby transforming the organizational structure from institute oriented to centre focused.

To build up a common CREE identity, we have organized regular CREE lunch meetings where internal CREE matters are presented, for example, upcoming CREE activities, upcoming information and deadlines for research proposals (to stimulate joint applications), news from ongoing CREE projects and CREE research output in the news. In addition, we have organized numerous CREE seminars with presentation from both CREE researchers and external researchers. We have also organized an annual CREE two-day research workshop. Here most of the CREE researchers are present, along with international researchers.

To stimulate cooperation between CREE researchers and CREE user partners, we organize two annual events. First, joint with CICEP we offer a policy-oriented seminar with presentations and comments from both researchers and user partners, along with roundtable debates. Second, we offer a dialogue seminar. The structure of this seminar has changed considerably over time. Initially, we let users choose topics for the dialogue seminar from a menu offered by CREE. Then we invited users to give comments on the talks of the CREE researchers. Later, based on one to two meetings with each user partner, we obtained a list of topics that user partners found very interesting for the dialogue seminar. We have of course followed this list, and obtained great feedbacks from the users. Finally, we have organized a few user-oriented seminars jointly with research partners at the faculty of law, University of Oslo.

During the last three years of CREE, we have offered an activity called CREE Hot Line where user partners can meet with CREE researchers to discuss methodological challenges in their own work, obtain references to the literature, get an introduction to a specific field within environmentally friendly energy, discuss policy implications with CREE researchers, etc. Based on these meetings, there could be a potential for a common project or a common research proposal.

Further, we have kept our user partners updated on CREE projects and papers through the regular CREE News Letter, thereby generating an interest in our research activities. Finally, when organizing research proposals, we have always been in contact with user partners, aiming at finding topics of mutual interest where CREE user partners can participate in the research activities.

5. Financing through the life of the centre

CREE funding 2011-2019

Total CREE centre funding incl. own funding.[1] (195.7 mill.)

	Cash[2]	In-kind (Own funding)[3]	Total
Host (Frisch Centre)		**51 429**	**51 429**
Research partners		**67 890**	**67 890**
UiO		7 850	
SSB		58 040	
Tilburg		2 000	
Companies	**3 800**		**3 800**
Statkraft	800		
Statnett	2 000		
Statoil	1 000		
Public partners	**4 230**		**4 230**
Miljødirektoratet	200		
UiO	4 030		
User partners		**4 311**	**4 311**
Gassnova		1 600	
Statkraft		630	
Statnett		630	
Statoil		315	
Miljødirektoratet		450	
NVE		450	
Energi Norge		138	
KLD		98	
RCN	**64 000**		**64 000**
Sum	**72 030**	**123 630**	**195 660**

RCN research projects and competence projects affiliated to the center.	**83 115**

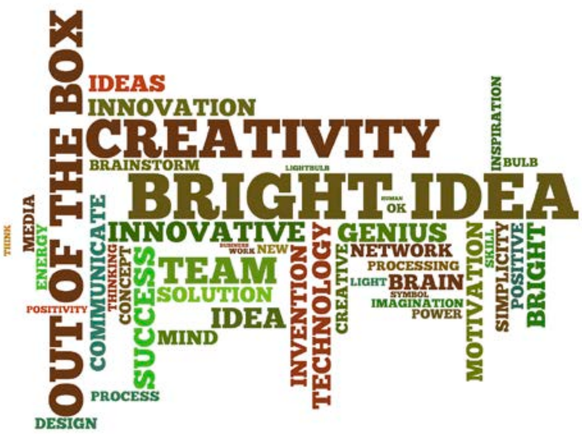
See Appendix 1 for more details.

[1] Own funding: Professional work that is beneficial to the CREE centre, but is not part of CREE's direct funding from The Research Council of Norway. Own funding should be at least 25% of the total budget of CREE.
[2] Cash: As a part of contribution from host and research partners.
[3] In-kind (Own funding): Project affiliated to the centre but not included in the CREE accounts.

6. Results – Key figures

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
Scientific Journal articles	9	20	22	32	18	25	23	25	18	11	**203**
Popular Science journal articles	5	11	13	7	7	17	1	5	16		**82**
Other scientific Publications	0	11	16	12	32	11	2	5	7		**96**
CREE's Working Paper series	6	19	27	20	24	15	11	13	11	2	**148**
Dissemination measures	29	88	95	77	90	83	68	63	87		**680**
PhD-degrees completed				1	2	4					**7**
Post docs					1	1		1			**3**
Master degrees		3	4	12	3	4	4	3	3		**36**

See Appendix 3 for details.



7. Research

7.1 Original research plan and development of research plan

Energy and climate policy is primarily focused on how to develop and utilize new technology and more environmentally friendly energy sources. This does not occur by itself, but is dependent on institutional and economic frameworks. The aim of CREE was to contribute to the collection and establishment of knowledge on how framework conditions affect both the energy market and technological development, including innovation and the diffusion of technology for renewable energy, energy efficiency and carbon capture and storage. The goal of the centre was therefore to develop better framework conditions and policy instruments designed to reach the goals established in national and international energy and climate policy.

From the kickoff of the centre, the research activities were structured around five working packages:

Work Package 1: The International Politics of Climate and Energy

Improving the current climate regime - Building on the UNFCCC and the Kyoto Treaty, can new institutions and mechanisms be added in order to increase incentives for abatement, joining and complying?

- Alternative treaty forms - What issues are raised by alternative treaty forms such as sector- based treaties or R&D collaborations?
- Dealing with non-signatories - How can abating countries best prevent carbon leakage from eroding abatement achievements?
- Equity issues - How can economic mechanisms, such as tradable emission permit markets, be used to deal with equity issues?
- Implications for energy markets policies - How are energy markets and policies affected under various global climate policy scenarios?

Work Package 2: Innovation and Diffusion Policy

- The relevance of the experience curve - Will environmentally friendly technologies become cheaper, or will the historical fall in costs stagnate at a non-competitive level?
- The optimal policy mix - R&D in environmentally friendly technologies can be spurred by a variety of instruments such as high permit prices, subsidies to private R&D, innovation prizes, etc.; how should governments design and combine the instruments optimally?
- Increasing returns to scale - How should governments deal with learning externalities and network externalities that may constitute a barrier for the diffusion of an environmentally friendly new product?
- CCS and R&D - CCS may be a key technology for achieving the atmospheric stabilization of GHG concentration – what does the optimal R&D policy for a small, open economy with a limited home market for CCS look like?
- Behavioral economics - Is it possible to identify types of cognitive costs that prevent environmentally friendly technologies from succeeding in the market?

Work Package 3: Regulation and Market

- What is a reasonable level of energy security and how do we ensure that it is achieved?
- What are the requirements of a network infrastructure when large amounts of wind and other intermittent energy sources are introduced into the system?
- How do we best ensure integration of national energy markets, both with respect to the physical infrastructure and to the system’s operation and regulatory oversight?
- How should measures to promote green energy be harmonized with the overall regulation of energy markets?

- When should we use market-based measures and when should we use other regulatory measures to increase the sustainability of our energy use?

Work Package 4: Evaluation of Environmental and Energy Policy Measures

- Rebound and adverse effects - How much of the initial energy efficiency gains are eaten up by increased consumption? Can the regulation of one good have unwanted effects on the consumption of close substitutes? How does the use of multiple policy tools affect behavior?
- Soft policy measures - How can we measure the effect of soft policies on preferences and behavior? How do these soft policies affect habits and attitudes, and do they affect the demand response to harder policy tools such as taxes and regulations?
- Environmentally friendly transportation - Have CO2 taxes on car fuel induced the purchase of more energy efficient cars? Does the increased use of biofuel and electric cars reduce emissions from road traffic?

Work Package 5: The Next Generation of Numerical Models

- National and international integrated models - Unilateral and international policies interact and demand development of economy-energy-environment models to improve the analyses of how different policies affect efficiency and emissions.
- Technological innovation and diffusion processes - We will model and empirically pin down the dynamic characteristics of the innovation and diffusion processes in a general economic model framework.
- Identification and quantification of policy effects - Identification of behavioral, technological and market characteristics will improve the empirical basis of our integrated models and policy analyses.
- Electricity market models - We will improve the modeling of the electricity market by integrating detailed technology-based bottom-up electricity market models with top-down energy market and macroeconomic models.
- Model Forum and Scenarios - We will establish a model forum for the development of energy and environmental economic models, and present energy and climate policies scenarios for the Norwegian economy.

This research plan was followed strictly until CREE received the midterm evaluation, which gave a lot of academic credits to CREE (assessed as a leading research group in Europe, maybe even globally), but also raised considerable concerns related to i) additionality of research, ii) extent of multidisciplinarity, iii) extent of user partner involvement, and iv) international cooperation. In 2016, CREE worked out strategies that addressed each of the concerns:

Strategies for additionality of research

- Improve the meeting places for CREE researchers, sub-contractors and users such that we get a dialog that benefits research.
- Cooperation on research proposals. New proposals should ideally include two or more research partners, one subcontractor (or researchers from another field), and involvement of user partners.
- Revise the research plan for 2016-19 to take into account recent research results, technological innovations and political developments.
- Revise the work packages of CREE to be in accordance with the new research plan.
- Synthesise the research at CREE once a year in connection with the annual reports.

Strategies for more multidisciplinarity

- Include researchers from other fields in research proposals
- Strengthen cooperation with our subcontractors
- Write joint research papers with researchers from other fields
- Continue to invite researchers from other fields to our seminars, workshops and conferences.

Strategies for better user partner involvement

- Develop the meeting places between user- and research partners in CREE to arenas for two-way communication.
- Increase user partner funding and participation in research projects.
- Increase the access to our research.
- Involve user partners in research by, e.g., encouraging subjects for Master theses and PhDs based on the arrangements in the RCN for industry and Government.
- Encourage user partners to spend some time at research partners and vice versa.

Strategies for international cooperation

- Strengthen our participation in EU-projects by taking initiatives to research proposals.
- The research collaboration between the Norwegian research partners in CREE and the international partner, Tilburg Sustainability Center, should be strengthened.
- Develop quantitative measurements for the international cooperation in the work plans and annual reports.
- Strengthen the cooperation with China.
- Take initiatives for research agreements at the centre level with international centres.

Strategies for better organization

- Expand the board by to include all user partners.
- Establish an International Scientific Advisory Board.
- Undergo a further revision of the organization of the centre in connection with the revision of the work packages and research groups.

These strategies led to a number of changes, in particular, reorganization of the centre research activities as four flagships (see 7.2); major changes in the key roles of the centre (for example, a new centre director); more user partners; more CREE board members; tailormade user activities, and a radical upgrading of the web site of the centre to make information on activities and access to various types of papers and reports easily available.

7.2 Research achievements

Flagship I: Radical emissions reductions in ETS sectors

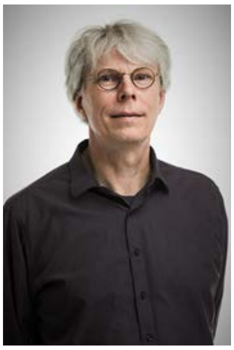
Overview

This flagship analyzed emissions reductions in the emissions trading (ETS) sectors. In addition to the EU member states, Norway together with Iceland and Lichtenstein, have joined the EU ETS. The ETS covers about 45% of the greenhouse gas emissions in the EU, and includes CO2 emissions from sectors such as power and heath generation, energy-intensive industries and civil aviation between the ETS countries. In Norway, a slightly larger share, about 50% of emissions, is covered by the ETS.

We concentrated our research on the power market, but we also studied other sectors. The aim was to understand the driving forces behind the regulations and the choice of regulatory instruments in these sectors. Further, we analyzed how they affect the Norwegian energy system and energy production, including investments in technologies and transmissions. We also studied how regulations can be designed to ensure socially warranted investment decisions. Finally, we took a further look at environmental costs of investments in the energy system.

Nils Henrik m. von der Fehr

This flagship was headed by Nils-Henrik von der Fehr (Department of Economics, UiO) and Snorre Kverndokk (Frisch Centre).



Snorre Kverndokk

Research questions and main results

The Flagship concentrated on five major themes called masts, where the first three themes study the electric power market.

<u>I.1 Intermittency, Flexibility and Security of Supply</u>

To mitigate greenhouse gas emissions, a transition from fossil fuels to renewable energy are necessary and also ongoing, in electric power production. Some electricity production from renewable energy such as hydropower, can easily be regulated to meet demand. However, most of the renewable production are based on solar and wind, and faces the problem of intermittency, i.e., the available energy used in the production varies over the day or week, as the sun is not always shining and the wind is not always blowing. Thus, to be able to meet the demand for electric power, some flexibility is needed. How this can be achieved may therefore be valuable for policy makers and for the society. Below we summarize the conclusions.

The flexibility of the market so that imbalance can be reduced is dependent on features of wholesale market exchanges – such as gate closure, market time unit and bid format. Changes in these features can increase the ability of markets to provide flexibility and reduce imbalances; however, such changes may increase transaction costs and hence the attractiveness of power exchanges, see von der Fehr (2018). Electricity pricing may also have an effect, and smaller geographical price areas may also increase flexibility through better transmission capacities.

One challenge for the European power market is a phase out of nuclear power. Using a numerical simulation model of the European energy industry (LIBEMOD), we find that a complete nuclear phase out in Europe by 2030 has a moderate impact on total production of electricity and only a tiny impact on total consumption of energy. Lower nuclear production is to a large extent replaced by more renewable electricity production, especially wind power and bio power, see Golombek et al. (2016a). With even more strict goals on renewable energy and energy efficiency in the EU (as agreed in June 2018), the share of the supply from renewable electricity and bio energy will be even higher in 2030, see Aune and Golombek (2018). This shows the relatively large flexibility of the European power market to adapt to new energy sources in the medium and long run.

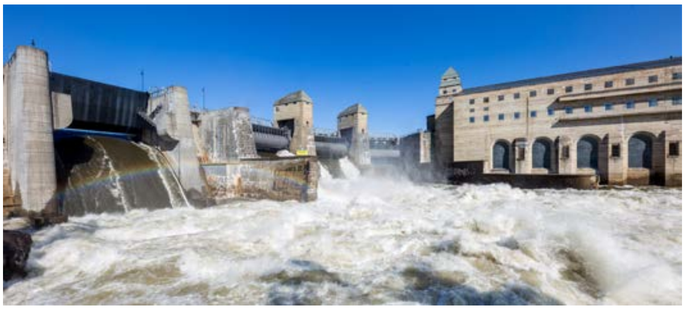
Different policy instruments can incentivize integration of more renewable energy into the power system. However, different instruments affect costs differently. One example is uniform subsidies that may lead to inefficient locations of wind farms and grids, as the producer then has limited incentives to take fully into account the investments costs of the subsequent need for increased grid capacity, leading to an inefficient choice of location, see Bjørnebye (2018).

I.2 Transmission and Integration

As mentioned above, intermittent power generation will vary by time and place, and will frequently be produced in areas that currently have limited transmission capacity. This will require more transmission capacity. The impact of weather stochasticity may be reduced by increasing the capacity of interconnectors (such as the one between the Nordic countries and the rest of Europe). Also, more efficient use of existing transmission capacity is warranted.

Integration of new renewable energy is important to reach renewable energy goals. One example of research in this line is our work on the integration of wind power in the Nord Pool Area and beyond. The main research question is how Scandinavian hydro capacity can cope with a large-scale expansion of wind power both in and around the North Sea, taking into account the possibility of pumped storage and the cost of building international grid interconnections that provide backup and regulate capacity to the countries in the Nord Pool area and beyond. We demonstrate that the exact regulating benefit of hydro depends finely on assumptions about availability of infrastructure, including pumped storage, see Førsund (2015).

One research question is if transmission system operators (TSOs) and regulators are able and willing to facilitate development of transmission networks, in particular where cooperation across jurisdictions is required. The current European model of transmission investment is largely decentralized and relies on the involvement of the nation's directly involved (say, those located on either side of an interconnector). Thus there is a lack of coordination, as this does not always allow for taking proper account of the considerable externalities of transmission investment and hence leads to inefficient (i.e. sub-optimal) investment. A subsidy to sustain the interconnector building is not sufficient to restore the best solution. To reach optimal investment without merging the two TSOs into an international operator that would internalize all the effects from its investment, we need a compensation to be paid to each TSO for the positive externality its internal investment creates abroad, see von der Fehr and Crampes (2018).



I.3 Distributed Electricity and Storage

New technology – including renewable generation, batteries and information and communication technology – is rapidly changing the role, not only of distribution networks, but also of distribution system operators (DSOs).

One research question we have been working on is if there are there barriers to the rolling out of new technologies. One barrier to diffusion of new technologies is commitment, i.e, that governments cannot commit to future climate policies. Policies to overcome this barrier are for instance emissions pricing with a state guarantee scheme whereby the regulatory risk is borne by the government and emission pricing combined with subsidies for upfront climate technology investments, see Fæhn and Isaksen (2016). Another barrier to diffusion of new technology is reluctance by households towards renewable resources such as solar energy, see Khan (2018).

I.4 Regulatory Instruments and Impacts

Reductions of emissions in the ETS sectors can be achieved with different instruments, including emissions quotas and taxes, quality standards, subsidies to green energy sources and an outright ban on the use of certain resources. Information of the impacts of different regulatory instrument is important for the efficiency and costs of achieving energy and climate goals.

What is the experience with the various instruments? Using a rich Norwegian panel data set, we have studied the effects of various environmental regulations on environmental performance of firms measured as changes in emission intensities. There is evidence that direct regulations promote persistent effects. Indirect regulations will, on the other hand, only have potential persistent effects if environmental taxes are increasing over time, see Bye and Klemetsen (2018).

Another example of the different impacts of policy instruments is our study on how renewable energy policy instruments affect competition on electricity markets, see von der Fehr and Ropenus (2016). We demonstrate that markets for green certificates allow generators with market power to squeeze the margins of their competitors, as a generator that is vertically integrated into network activities might do. Further, we find that whether or not a dominant firm is vertically integrated into network activities, it can disadvantage competitors in the renewables segment by distorting certificates prices, thereby inducing cost inefficiency in the generation of renewable energy. We compare green certificates to a system of feed-in tariffs, where a similar margin squeeze is not possible, concluding that these policy instruments have very different implications for competition and overall efficiency.

We have written several studies on the effects of carbon taxation. One example are studies on carbon taxes used on traded goods to reduce emissions when not all countries have restrictive climate goals. One such study concludes that such tariffs do reduce foreign emissions, but can increase rather than decrease the global cost of emission reduction. The main effect of carbon tariffs is to shift the economic burden of developed - world climate policies to the developing world, see Böhringer et al. (2016).

I.5 Carbon capture and storage

Carbon capture and storage (CCS) may be necessary to contain global warming below 1.5 or 2 degrees Celsius, as is the current political ambition. Adoption of CCS technology in the power sector, however, has by been far behind predictions. Research results on the barriers to implementation may therefore have a large impact on policy design and, in the end, on whether we are able to reach the climate goals specified in the Paris agreement.

An interesting research question is therefore, why has the technology not been implemented in a large scale as many model scenarios show is necessary to reach the Paris goals in a cost-effective way? We have written a survey article where we go through the arguments in the literature for the low implementation of CCS, see Golombek et al. (2019). In particular, we point to market imperfections in the three markets capture, transport and storage as a main reason, as well as the use of a large number of policy instruments to reach the climate targets in the EU. While a price on CO_2 is necessary for CCS to be implemented, the EU has targets for renewable energy and energy efficiency in addition to the emissions targets. This reduces the CO_2 price substantially in the EU-ETS, see Aune and Golombek (2018). One of our studies show that a substantial CO_2 tax is necessary for CCS to play an important role in the European energy market. According to our model simulations, subsidies are necessary unless there is a very high carbon tax. Our simulations show that with a tax of $90 per ton CO2 in 2030, CCS will be installed without subsidies, see Golombek et al. (2011). This is far above the present carbon price in the European permit trade system.

Can CCS be economically profitable without government support? Based on our studies, this is likely not the case in the near future. A study on the design of support shows that subsidies to CCS are more efficient if they are provided to development of the CCS technology in Europe than to the use of the technology, see Golombek et al. (2016b). Support to development gives Europe a strategic benefit, while support to use will benefit all developers. In addition, support to CCS in coal production should be larger than for gas production due to the higher CO2 content in coal than gas, and du to terms of trade effects. Support to CCS can, however, only be justified if there are market imperfections or barriers so that the investors or owners of power plants do not find CCS profitable even if it is socially optimal. We find that such support may be justified as there may be network effects in the energy market, and this may be a barrier to the implementation of CCS, see Velten (2017).

*

To sum up, the research in this Flagship finds that the energy market faces several challenges due to the transition to renewable energy. More flexibility is needed to reduce possible imbalance in the market. This again requires increased investments in transmission capacity. Another challenge is that many decisions are decentralized. Policy instruments therefore, have to take this into account to avoid inefficiency. A final important challenge is how to achieve negative emissions to meet the long-term climate targets. Even though CCS is regarded as a necessary technology in the long run, it is barely implemented due to lack of appropriate carbon pricing as well as support. This also points to the design of policy instruments as introducing many regulations at the same time as in the EU, reduces the carbon price and creates incentives for other energy investments than in CCS.

Flagship II: Environmentally friendly transport

Overview

Norway has committed to a 40% reduction of greenhouse gas emissions from the non-ETS sectors by 2030. Transport makes up a major share of Norwegian emissions in the non-ETS. Although there will be flexibility available for the non-ETS sector across the EU members, the Norwegian Parliament has announced that they aim for radical domestic emission cuts in transport.

Cathrine Hagem

The sustainability of transport can be improved by the following measures: i) reducing the total amount of traveling, ii) modal shift, e.g. from road to rail, and iii) by introducing new technologies (e.g., electric vehicles and increased fuel efficiency). For policy it is important to obtain the right balance between the measures. It is not only the direct cost of the measures that must be taken into account, but also potential market imperfections and external effects.

The Flagship was headed by Cathrine Hagem, Statistics Norway.

Research questions and main results

The Flagship concentrates on three major themes.

<u>II.1 Electrification of the private road transport and the electricity market</u>

Norway is a pioneer when it comes to electrification of the car fleet. In 2018, 30 % of new cars were zero-emission cars, of which almost all were battery electric cars. Electrification of the car fleet will increase the interdependence between the transport system and the electricity market. This will require new policy measures and improved coordination and collaboration between different policy makers and institutions. The pricing of electric cars charging may have a lot to say for the success and costs of the transition to an electrified car fleet.

EV-friendly transport policies increase the demand for power, thus challenging the distribution grid's capacity, while electricity policies immediately impact on the costs of driving EVs. If enough EV-owning agents charge during power peak hours, costly grid expansions may be needed. In a study we examine how the distribution grid company in Norway can respond in order to mitigate these costs with different pricing schemes and how this in turn affects the transport equilibrium, see Wangsness et al. (2019). It is found that applying peak tariffs for the grid will help support a better balance between investment costs and EV-owners' disutility of charging during off-peak hours.

The organization of the charging market may be crucial for the market diffusion of electric cars. In a CREE study we show that a charging network with incompatible high-speed charging systems will unambiguously imply slower phase-in than a network in which all cars are compatible with all charging stations, see Greaker (2019).

Electric vehicles are dependent on electricity supply from the grid, and they will increase total electricity demand. On the other hand, bidirectional chargers (Vehicle-to-grid, V2G) imply that

EVs may also store and supply electricity to the grid. This can smooth out daily variability in demand and supply of electricity from other sources. The larger battery, the larger possibility to store and supply electricity from the EV. Moreover, the EV can also help balancing the grid by supplying quick power when there is a local imbalance. In CREE we have address the following research question: what is the impact of V2G on the electricity market, see Hagem et al. (2019)? To answer this question, we integrate a model of EV users' choice of battery capacity with a simple model of the electricity market. We show how consumers' optimal battery capacity choices affect the equilibrium electricity prices during peak and off-peak hours, and optimal investments in power plants. One finding is that viable V2G solutions increase welfare as the need for investment in backup power capacity decreases.

II.2 Policy instruments for promoting sustainable private and commercial transport

Over the past years, many countries have been greening the car fleet through revisions of purchase taxes, road taxes, or by special privileges for low emission car owners.

In CREE we have exploit the variation in the stringency of vehicle fiscal policies across EU countries and time to address the following research question: to what extent have national fiscal policies contributed to the decarbonization of newly sold passenger cars, see Gerlagh et al. (2018)? The study is based on a data set of vehicle-specific taxes across 15 countries over the years 2001–2010. The study finds empirical evidence that fiscal vehicle policies significantly affect emission intensities of new bought cars. There is evidence that especially the CO2-sensitivity of registration taxes and the level of the fuel taxes are important determinants of the emission intensity of new cars. The diesel–petrol substitution induced by changes in relative taxes for diesel versus petrol cars is an important factor for the average fleet's fuel efficiency. The study also finds higher CO2-intensities with increasing income and a clear convergence pattern between EU countries.

In CREE we have also studied the implication of the Norwegian reform for vehicle registration tax in 2007. The results show that average CO2 intensity of new vehicles was reduced in the year of the implementation of the reform by about 7.5 g of CO2/km. This reduction is the result of a 12 percentage points drop in the share of highly polluting cars and of an increase of about 20 percentage points in the market share of diesel cars, see Ciccone (2014).

A tax on fuel is implemented in many countries to reduce both greenhouse gas emissions and other negative externalities from road traffic. The road user charge on fuel can partly be avoided by purchasing fuel-efficient vehicles. This may lead to too much investment in fuel-efficient cars and may call for heavier tax on fuel-efficient vehicles, see Bjertnæs (2019).

The large share of electric vehicles of new cars in Norway is induced by a set of policies that include tax exemptions as well as various driving privileges, like the use of bus and collective lanes in cities, exemption from parking fees in city centers, and often battery charging at zero cost. In some of CREEs research it is argued that this policy leads to very high cost for small emission reduction, and that it may lead to more driving causing other externalities, see Holtsmark and Skonhoft (2014).

Although electrification is a viable solution for passenger cars and light-duty vehicles, it is less so for heavy duty vehicles under present technologies. Different policies for inducing less emission intensive commercial transport has been proposed, including both subsidy-schemes and tax-schemes. In CREE we have analyzed the optimal environmental policy for the commercial transport sector in Norway, see Segiet (2018). The result indicates that when the government can commit to the level of tax in the future, or when there is no strategic action when the government cannot commit, the subsidy for the commercial transport sector in Norway is not a cost-effective climate policy and a tax on CO2 emissions is more desirable. However, when we assumed that the government was not able to commit to a certain level of the tax in the future and firms acted strategically, the optimal policy involved a subsidy on capital.

Fuel efficiency improvements in the transports sector leads to less emissions per of unit output (transport services) and can play an important role on the path to a decarbonized economy. A popular policy instrument to reduce oil consumption has been fuel efficiency standards for new vehicles, and there have been significant improvements in energy efficiency globally over the last decades. However, fuel efficiency measures may be less effective than expected due to the so-called rebound effect; fuel efficiency improvements lower the cost of energy services, thereby encouraging more use of those services. In CREE we have developed a model to investigate the effects in the oil market of fuel efficiency improvements in the transport sector, see Aune et al. (2017). One conclusion from that study is that the rebound effect has a noticeable effect on the transport sector, with the magnitude depending on the oil demand elasticity. In the benchmark simulations, almost half of the energy savings may be lost to a direct rebound effect and an additional 10% to oil price adjustments. If market power is present in the oil market, the directions of change in consumption and price might contrast with those in a competitive market, see Kverndokk and Rosendahl (2013).

Another research question we have address in CREE is whether the promotion to purchase and use electric cars change the driving pattern of the owners of fossil cars, see Kverndokk et al. (2019). Evidence from a survey indicates that Norwegian policies to promote emission free cars have moderately reduced fossil car driving.

II.3 Biofuels in road transport

Biofuel and other forms of bioenergy has been considered as an important alternative to fossil energy. For 2020 there is a biofuel blending mandate of 20 per cent in the in the transport sector in Norway.

Bioenergy is usually considered as carbon neutral. However, food-crop-based biofuels has been criticized for the upward pressure such production has put on food prices. It can also cause greenhouse gas emissions related to growing and processing, and emissions due to land use changes when converting grazing land or forest land to land for producing crops for bioenergy. An alternative to converting grazing land or forest land into land for growing suitable crops for bioenergy production is to use the harvest from standing forests to produce bioenergy. So-called second-generation liquid biofuels can be produced from processing cellulosic biomass. However, one can argue that wood harvesting is not a carbon neutral policy. A higher level of harvest leads to a lower stock of carbon in the forest. So even though the second-generation biofuels replace petrol in the transport sector, and thereby reduce emissions, the carbon stock has decreased, and hence carbon has been released. For the Norwegian type of forest, it takes a very long time before the carbon stock in the forest is restored, see Holtsmark (2012).

There is a tradeoff between forest as a source for producing bioenergy and as a carbon sink. An unregulated market will not yield the social optimal balance, and thus market intervention through optimal subsidies (on carbon sequestration) and taxes (on fossil fuel emissions) are called for, see Hoel and Sletten (2016).

The results for the analysis of the impact of a biofuel mandate are highly dependent on whether the analysis is static or dynamic. It is well known that a biofuel mandate is equivalent to a revenue neutral combination of a carbon tax and a subsidy on biofuel production. In a static setting, a blending biofuel mandate will lead to less emissions for fossil fuels and increased use of biofuels. However, considering that oil is a non-renewable resource, a blending mandate may not have any effect on accumulated oil consumption. It will however, shift the consumption pattern over time. Extraction of oil is postponed because of the blending biofuel mandate. This has beneficial climate effects, see Greaker et al. (2014).

Flagship III: Green innovations and utilization of smart technologies

Overview

Achieving ambitious environmental and climate goals requires broad adoption of environmentally friendly and energy efficient technologies in homes and businesses. The aim of this Flagship was to increase our understanding of how policies can motivate research, development and diffusion of both low-emission technologies and technologies aiming at lowering energy consumption. What impact will economic factors, habits and norms have on development and utilization of new technologies? How do firms and consumers use and respond to new technologies? To what extent does adoption of the new technologies reduce energy demand?

Bente Halvorsen

The Flagship was led by senior researcher Dr. Bente Halvorsen from Statistics Norway.

Research questions and main results

The research on this Flagship has focused on two major themes: Innovation and diffusion of green technologies, and how green technologies affect energy use. Research and Development (R&D) in a firm creates new knowledge, which also benefits other firms, and thus entails a positive externality in society. A main reason to support private R&D is that the innovator will in general not be able to appropriate the full social benefit of the innovation. In economics, this is usually referred to as the appropriability problem, and it provides a rationalization for the government to support private R&D. This research examines how policies should be designed to overcome the appropriability problem. An important aspect of the research is to see the design of Research, Development and Diffusion (R&D&D) instruments in relation to other environmental policies. A key research topic is therefore the optimal design of the R&D&D policy instruments.

Development of new and more environmentally friendly technologies is a premise for achieving a green transition, but no guarantee. To ensure the desired development, the technology needs to be widely spread and used in the desired way. As most economic decisions are left to consumers and producers, the diffusion and use of an environmentally friendly technology depends on how it meets the wishes and needs of the public, given their preferences, costs considerations, income/profits and what alternative technologies are available. An important research topic is thus how these new technologies are spread and used in society, and how this affects the use of different energy sources.

<u>III.1 Innovation and diffusion of green technologies</u>

Like other types of R&D, environmentally-friendly R&D is also characterized by market failures and obstacles. In many regions, renewable energy targets are a primary decarbonization policy. Another instrument that might trigger more use of renewable energy is simply a subsidy on use of renewable energy and/or on production of renewable energy capital. Fischer et. al (2018) demonstrate that under imperfect competition upstream, subsidies may improve welfare both globally and nationally. From a national point of view, Fischer et. al finds that upstream subsidies (support to producers) are preferred over downstream subsidies (support to users) of renewable energy.

We have also conducted a study on how patents work together with R&D subsidies and climate policy (Gerlagh et. al, 2014). If the emission price is set according to the marginal damage of the emissions, the optimal clean energy R&D subsidies are initially high, but then fall over time.

Whereas research subsidies are standard policy instruments, innovation prizes have not been much discussed in the literature. With an innovation prize, the actor receives an amount of money from the regulator/government if he/she succeeds in developing a new technology that meets some pre-specified technical conditions. The innovator invests in R&D to develop a new technology, being aware that an innovation prize will be received if he is successful.

Golombek et al. (2020) show that the regulator can design an innovation prize that solves the appropriability problem. The paper compares a market good innovation—to develop a more efficient technology to produce a standard market good—with an environmental innovation—to develop a more efficient abatement technology—that has the same potential to increase the social surplus. In the first-best outcome, which can be achieved by offering an R&D subsidy and a diffusion subsidy, the R&D subsidy should be greatest for an environmental innovation, whereas the diffusion subsidy should be greatest for a market good innovation. The ranking of the two types of subsidies reflects that the appropriability problem is greater for an environmental innovation than for a market good innovation.

Design of instruments to promote more Carbon Capture and Storage (CCS) is another key research topic. This technology has been seen by the IEA and the EU as having the potential to bridge the gap between the current carbon-based society and a future low-carbon society. Using CCS electricity technologies, either with coal or natural gas as the fuel, may reduce emissions by as much as 90 percent relative to standard fossil-fuel based technologies. One main disadvantage of CCS is high costs. These may, however, be lower through R&D. An important question is then whether CCS should be prompted through subsidizing the producers of CCS technology (upstream subsidy) or through subsidizing the use of CCS technology (downstream subsidy). Golombek et. al (2016) have shown that for the EU it is optimal to offer an upstream subsidy to the EU producers, but no downstream subsidy. By offering an upstream subsidy to the EU producers, production is shifted from the non-EU producers to the EU producers, thereby shifting profits to the EU producers and at the same time gaining consumers because total production increases.

Econometric analysis on the efficiency of Norwegian policy instruments to promote R&D in firms are also conducted on this Flagship. Klemetsen et. al (2018) study empirically how environmental regulations may trigger more environmentally friendly R&D, measured by number of patents. The results indicate that indirect regulations will only have potential persistent effects if environmental taxes are increasing over time. Thus, technology standards and non-tradable emission permits may be a useful complement to market-based instruments in spurring innovation in environmentally friendly technologies (see also section 3.1).

Klemetsen (2015) examines the impact of R&D tax credits and direct R&D subsidies on Norwegian firms' patenting. For environmental patenting, the study found no significant effects of tax credits, whereas the effects of direct subsidies are large and significant.

Some argue that environmental R&D should take precedence over market goods R&D in subsidy programs. Unless there is reason to believe there is a systematic difference in the magnitude of these market failures between the two cases, these market failures should not lead to any systematic difference in the incentives for environmental R&D and for market goods R&D. Greaker and Hoel (2011) discuss a potential difference between the market goods case and the environmental technology case, namely the way in which demand for the new innovation is determined. They show that the assumption that incentives for environmental R&D are lower than incentives for market goods R&D is not generally true. This holds independent of the type of environmental policy instrument being used. Greaker et. al (2017) illustrate another situation where the governments should prioritize clean R&D. Dealing with major environmental problems requires a R&D shift towards clean technology. In the case where most researchers are working with developing clean technology, both productivity spillovers and the risks of future replacement increase. Consequently, the gap between the private and social values of an innovation is greatest for clean technologies as compared to other technology developments.

To sum up, the research finds that both innovation prizes, technology standards and non-tradable emission permits may be important policy instruments to trigger more environmentally-friendly R&D as an alternative to, or in combination with, more traditional subsidies and taxes. The research also finds a clear preference to up-stream (producer) subsidies as compared to down-stream (user) subsidies to enhance the environmentally friendly R&D activities in the economy.

III.2 Green technologies and energy use

The installation and utilization of environmentally friendly technology in households and firms is necessary for accomplishing the green transition. Thus, the other main field of research in this Flagship is how new technology is used in households and firms, and how this affects energy consumption. One of the major topics of this research has been rebound and adverse effects of energy efficiency measures on energy consumption. These effects occur because increased efficiency decreases the cost of using energy to produce goods and services. In our research, the rebound effects have been exemplified by the effect on household energy consumption of having invested in a heat pump. We have conducted both economic and anthropological analyses on this topic (Halvorsen et. al 2016; Winther and Wilhite 2015; Halvorsen and Larsen 2013; Bøeng et. al 2013). We find large rebound effects of heat pump ownership, and on average, electricity consumption is unchanged after installing a pump. This is partly due to reduced use of alternative fuels like firewood and fuel oils, but also a result of an increase in the heated area and higher average indoor temperature in the residence.

These findings seem to be robust with respect to analytical approach, as we find the same effects both in economic and anthropological analyses. Similar results are found in a study analyzing

factors effecting residential indoor temperature, where we find that the indoor temperature varies with the heating equipment (Halvorsen and Dalen 2013). Households with a common central heating system is the group with the highest indoor temperature, followed by households with a heat pump. On the other end of the spectrum, households that use a lot of firewood for heating have the lowest average temperature in the living room on cold winter mornings.
Another important topic of this research has been behavioral responses to soft policy tools (i.e. to increase awareness) to reduce energy consumption. Using anthropological methods, Westskog et. al (2015) have analyzed how households relate to electricity meters showing energy consumption by various activities. They find that households are concerned with the information provided, and especially seems to appreciate information about costs.

Winther and Bell (2018) use qualitative data from Norway and the United Kingdom to analyze how the new technology of in-home display monitors may affect social practices and relations. A key question is whether the display triggers a new practice of monitoring electricity consumption. Among both groups, many participants gave detailed accounts of how they monitored the displays. The regular consulting of displays suggest that monitoring electricity became a new routine for many of the participating households. This conclusion was strengthened by the observation that the Norwegian flat-owners continued to use less electricity than their neighbors up to one year following the installation of the new meter display.

A new technology may only affect energy consumption if it fulfills the wishes and needs of its user. The ability of the technology to reduce energy use thus depends on the publics preferences. We find that households concerned about costs tend to invest in heat pumps more than others, whereas environmental concerns are paramount in explaining purchase of wood pellets stoves (Lillemo et. al 2013). We also find that the main reason very few households chose to purchase a pellets stove, despite the investment subsidy, is that alternative heating equipment are viewed as better or more desirable (Lillemo et. al 2011). A study comparing the distribution of electricity on different end-uses for the years 1990, 2001 and 2006 find that electricity for basic use, such as washing, cooling of food and heating of water, does not vary much over the period (Dalen and Larsen 2015). Total energy consumption for heating purposes is also quite stable over the period. However, electricity for heating may vary considerably across years, depending on relative energy prices and temperature.

With respect to how policies affect technology choices in firms, Storrøsten (2012) finds that tradable emissions permit and an emissions tax affect the technology choice differently under uncertainty. A tax encourages the most flexible abatement technology if and only if stochastic costs and the equilibrium permit price have sufficiently strong positive covariance, compared with the variance in consumer demand for the good produced. Moreover, the regulator may not, in general, be able to design tradable emissions permits and an emissions tax such that the two regimes are equivalent when technology choice, uncertainty and the product market are considered. Finally, the firms' technology choices are socially optimal under tradable emissions permits, but not under an emission tax.

To sum up, the research conducted illustrates that policy measures may help facilitate a green transition with respect to energy use, but that the policy measures must be carefully designed to reduce behavioral barriers and avoid undesired side effects, such as rebound effects. Our research indicates that subsidizing the purchase of a particular equipment is no guarantee for its diffusion if the potential buyers perceive alternative technologies as superior or more desirable. This was the case for pellet stoves, where the Norwegian public preferred to buy heat pumps instead despite a subsidy on pellet stove purchases. Given that a household or a firm has chosen to install more energy efficient equipment, we find (in some cases) very strong rebound effects, as the new technology may change how they choose to use energy after the equipment is installed. Some of these changes may be desired (e.g. increased energy efficiency) whereas others are more discussable (e.g. increased share of electricity for heating). We also find that increased information about personal electricity use in the form of more advanced meter displays affects how the households use electricity in their homes, resulting in reduced consumption.

Flagship IV: Towards the low-emission society

Overview

While Flagship I, II and III focus on specific sectors and technologies, this flagship aimed at taking a comprehensive view by focussing on larger entities; nations, regions and the world. Changes in behaviour and investments towards a more environmentally friendly and less carbon-intensive energy use are largely affected by policies. Approaches in Flagship IV embrace theoretical and numerical models of technological, behavioural and political responses to challenges in the energy-environment-climate nexus. It is also pivotal to learn from experience by using empirical methods and experiments of behavioural responses. There is a need to understand the political, legal, economic, behavioural and technological motivations and obstacles for alternative pathways.

Taran Fæhn

The flagship Towards the low-emission society embraces three sub-themes–or masts:

1: Greening the economy

2: National and international climate policies and treaties

3: Barriers and opportunities to transformation.

This flagship was headed by Senior Researcher Taran Fæhn at Statistics Norway.

Research questions and main results

<u>IV.1 Greening the economy</u>

This mast addressed economic structures nationally and globally and their transitions from fossil-fuel based industries and petroleum dependency to green energy and clean activities. Technological change is naturally a big part of this.

Reducing demand for fossil fuels

Analyses of demand changes in the fossil fuels markets have to a large extent been based on models. For instance, the LIBEMOD model of the European energy markets has been simulated to look at the impacts of the EU climate target in 2030 on imports of natural gas from Russia, showing that as EU demand for natural gas is moderately affected, the imports from Russia will only increase slightly, see Aune et al. (2015a). In another study of the gas markets, we have looked at the impacts on arctic gas production of phasing out coal and promoting renewables in the European power sector in 2050 in line with the 2 °C scenario, see Lindholt and Glomsrød (2018). We have used the model FRISBEE that has a detailed modelling of the supply side of the gas market. That study finds that the arctic gas production decreases significantly by 2050, and a small decrease is also found for Russian extraction.

PETRO2 is also an oil market model where the demand side and the intertemporal dynamics of the oil market can be captured. The model is used for studying two different demand-side climate actions, see Aune et al. (2017). First, a global phasing-out of subsidies to transport fuels have been examined. Second, scenarios with increased transport fuel efficiency is explored. Both studies revealed rebound effects and carbon leakage to other sectors and countries.

Yet another type of model that takes an economy-wide perspective (so-called Computable General Equilibrium – CGE – model) is used in Böhringer et al. (2014, 2018) to consider carbon leakage when taking into account the strategic behaviour of OPEC in the oil market. They show that OPEC's response to EU's climate policy can be large, and hence including these responses can be important for the results. It is shown that if OPEC believes the EU is pursuing a quantity target, it will counteract a European carbon price reduction by reducing production. By doing this, the producers shift the rents from taxation from the EU to themselves. The authors show that the response might be sufficiently strong for the carbon leakage to be negative.

Reducing supply of fossil fuels

CREE research has contributed significantly to the knowledge frontier when it comes to supply side climate policies. Recently, nine CREE researchers published a Science article posing arguments for redirecting climate policies toward fossil fuel producers directly by capping the flows of extraction and restricting the stocks of resources available for exploration, Asheim et al. (2019). Four arguments are given: To enhance the effectiveness of the Paris Agreement, to insure against the failure of the Agreement, to stimulate green R&D and to get fossil fuel producing countries and companies on board as capping supply will increase fossil fuel prices. A treaty among producers need not be costly and could help reduce the costs of the required transition to a low-carbon economy. Numerical contributions support the idea. Unilateral climate policies will in general minimise costs if directed partly to the demand-side and partly to the supply-side. In the Norwegian case, we find that the optimal is to do about 2/3 of the measures as supply-side cuts in the production of oil, see Fæhn et al. (2017).

Two contributions from CREE have extended the analysis to consider demand-side/supply-side combinations when accounting for intertemporal changes of extraction. It is a well-known mechanism that expectations of future demand-side policy tend to increase present extractions (the so-called green paradox). Hagem and Storrøsten (2018) consider carbon leakage in a dynamic framework and show that the green paradox argument strengthens the case for supply-side policy. The reason is that commitment to future reductions in extraction by one country/coalition provides incentives for producers in other countries to delay extraction to increase overall profits. For similar reasons, Hoel (2013a) argue that supply-side policies are less likely to create the green paradox that can result from demand-side policies. Specifically, there will be no green paradox if supply-side climate policies are aimed at high-cost carbon reserves. If instead low-cost reserves are removed, the possibility that both early and total emissions increase cannot be ruled out. Harstad (2012a) further develops the arguments made by Hoel and shows that supply-side carbon leakage can be avoided completely if marginal fossil energy resources can be bought internationally and conserved.

IV.2 National and international climate policies and treaties

In this flagship, national climate policies are limited to sector-overarching climate policy goals and instruments. Emissions outside of the EU-ETS has been the main focus. The ETS is thoroughly addressed in Flagship I. International policies in focus have primarily been at the EU level or at the global level. The research in this field has mainly focussed on what will be the costs and distributional impacts of meeting greenhouse gas emission targets, what are good choices of instruments and how will they affect behaviour.

Norwegian climate policies

In the Norwegian setting, national climate policy goals have until now been formulated in ways that allow for buying quotas or otherwise obtain credits by implementing emission cuts abroad. An important discussion has therefore been what are the pros and cons and a sensible balancing of measures at home versus abroad.

Norway's national emission reduction target for 2030 is established by law and restates the country's Nationally Determined Contribution (NDC) in the Paris Agreement: a 40 percent reduction compared to the 1990 level. Norway has been part of the EU-ETS since 2008. Recently, the non-ETS target has been linked to that of the EU, and Norway's share of the European efforts imply a 40% cut from the 2005 emission level. EU bans the purchase of allowances from outside the EU, which Norway has previously relied heavily on for meeting the targets in the Kyoto Agreements. The mechanisms most exploited until now are the Clean Development Mechanisms (CDM): Several early CREE contributions have assessed them to be ineffective and unfair, see Rosendahl and Strand (2011), Hagem and Holtsmark (2011) and Strand and Rosendahl (2012).

On the other hand, the common implementation with the EU now decided gives Norway access to several European flexibility mechanisms, vis-á-vis the ETS, vis-á-vis the Land Use, Land-Use Change and Forestry (LULUCF) sector, across time, and last but not least, across borders within the non-ETS sector. The latter is most subject to discussion now. There is still large uncertainty as to what specific mechanisms will be available. To date, the EU has not established any institutions to organise and monitor this trading. Moreover, no one knows what the prices will be for such emission allowances. In a study of a completely flexible trading of non-ETS allowances across borders, simulated prices well exceed the permit prices in the ETS – amounting to around 200€/t CO_2 in 2030, see Aune et al. (2015b) and Aune and Fæhn (2016). However, when accounting for the other flexibilities and comparing with more updated reference paths from the EU, the prices appear to become lower, see Bye et al. (2019).

The prices of European allowances, both within and outside of the EU-ETS, will not least be sensitive to what other policies will be implemented. In a recent study, a comprehensive assessment of the EU climate and energy package is offered, with its three main targets: lower greenhouse gas emissions, higher renewable share in final energy consumption, and improved energy efficiency. The study finds that the renewable and energy-efficiency targets have been set so high that the derived emissions reduction (50 percent) exceeds the EU climate target (40 percent). Hence, there is no need for an EU climate policy. Put differently, the allowance prices both within and outside the EU-ETS will render zero. The abatement cost of the full package will however become high, see Aune and Golombek (2019). This analysis is a good example of how interplays among various instruments and goals counteract or overlap each other and render the overall policies unnecessarily expensive. This subject has also been addressed in earlier CREE research, particularly emphasising Norwegian evidence and the Norwegian debate about multiple goals and instruments, see Bøeng and Rosnes (2013), Hoel (2013b), Bruvoll and Dalen (2015) and Bye et al. (2019).

Irrespective of assumptions and inclusions in the computations of EU allowance prices, fulfilling the non-ETS target by domestic emission cuts, only, are found to be dramatically more costly than buying allowances within Europe, see Fæhn and Isaksen (2016) and Aune and Fæhn (2016). These findings are relevant for the political decisions on Norway's ambitions within own borders. Essential arguments for concentrating efforts at home are that transition takes time and that innovation, learning and R&D is needed domestically in order to be prepared for increasing global and national targets in the decades to come. Similar arguments can be used for domestic regulations of emissions covered by the EU-ETS on top of the allowance price, even if the immediate mitigation impacts of such interference will be more or less fully counteracted by increased emissions elsewhere in the market. Recently, CREE projects have started that address the trade-off between emission cuts in the shorter and longer run.

Unilateral climate policies and carbon leakage
Low-emission strategies of single countries or coalitions like the EU bear the risk of adverse impacts on competitiveness, trade and carbon leakage. CREE has been very active in the field of carbon leakage and what are effective and feasible countermeasures. Carbon leakage can occur both via the final goods markets and via the energy markets. For the latter, see the discussion of fossil fuel policies from the demand and supply side above.

Leakage via final goods markets is associated with domestic firms losing competitiveness vis-á-vis less regulated, higher-emitting firms abroad. CREE's contributions are mainly based on large-scale global models, see Carbone and Rivers (2017). Theory suggests that border carbon adjustments (BCA), i.e., import tariffs and export subsidies on the carbon embodied in trade, can be used as an instrument to improve the economic efficiency of unilateral emissions pricing policies.

A more common action is to rebate domestic firms for the tax payments in proportion to their output. This is known as output-based rebating (OBR) and is fairly equivalent to the free allocation of quotas practised in the EU-ETS. Computations usually find OBR to be less effective but more feasible legally and politically from a free trade perspective than BCA, see Böhringer et al. (2012). However, recently, the European Commission has become more concrete about implementing BCAs. Both types of instruments have been studied in CREE by large-scale models. One study investigates how optimal OBR policies depend on the actions of large trading partners, see Böhringer et al. (2017a). Two analyses suggest combining OBA with a consumption tax. They show that this combination is equivalent with the more efficient BCA option, and that under uncertainty, these policies constitute a hedging option against carbon leakage, see Böhringer et al. (2017b) and Böhringer et al. (2019). Other studies compare various BCA designs and show that the choice typically will have to involve a trade-off between efficiency and administrative costs, see Böhringer et al. (2012). The most efficient would be to incentivise abatement responses among exporters in trading partner countries; however, such designs are complicated and relatively costly to administer as each shipment would need to be individually treated, see Böhringer et al. (2017c).

International climate negotiations

The international negotiations on climate change mitigation is riddled with severe prisoner's dilemma problems, i.e. curbing climate change would benefit all countries, but individual countries' incentives to cut emissions are weak. The costs of mitigation are borne individually, while the gains are shared by everyone. Such a situation will lead to emission reductions that fall short of the globally optimal level of emission reduction. CREE has contributed significantly to the research literature on designs of agreements and organisation of the negotiations in order to obtain robust and ambitious results. These contributions mainly apply game-theoretical models. In an article, the literature covering the period before the Paris Agreement is reviewed, see de Zeew (2015). The basic picture is not optimistic: If there are large gains of cooperation, the stable coalition is small. There is a general view that top-down general agreements on emission reductions such as the Kyoto Protocol have not and will not obtain sufficient participation and mitigation.

Several articles from CREE have broadened the negotiation game to include development and transfer of low-carbon technologies, see Hoel and de Zeeuw (2014), Harstad (2012b; 2016) and Harstad et al. (2019). If countries can share the R&D costs for the technological development, this additional positive externality will strengthen the incentives to cooperate. If the new technology spills over to other countries, an extra benefit occurs as these other countries will emit less. There is a complex relationship between abatement commitments and technological decisions. For instance, investments in green technologies by one country today will reduce the incentives of others to invest tomorrow. Technological investments will also foster pressure in the negotiations for stronger commitments. Technological positive spillovers can make it more difficult to design self-enforcing agreements. The length of the agreement is an important aspect.

Longer agreement periods will incentivise investments, however, will be less robust to changes in surroundings along time. With weak patenting systems or other discouragements for investing in innovation, long agreement periods are pivotal.

The success of international climate agreements depends on credible enforcement institutions, i.e. possibilities to legally prosecute and penalise if the agreement is violated. Both economic and legal perspectives are taken by CREE researchers on drivers determining the enforcement institutions and solutions to how systems can be designed, see Hovi et al. (2012), Ulfstein and Voigt (2014), Voigt (2014a) and Battaglini and Harstad (2019).

The Paris Agreement in 2015 represented a significant change in design and process from the previous Kyoto Agreements. A main change was that pledges were given from each country independently of their summed impact. The main benefit was that almost every country participated and determined their NDC. However, the total impact in terms of mitigation is most probably far from what is needed to meet the overall, long-term temperature goal of staying well below 2 degrees of global warming. A couple of recent contributions from CREE analyse the features of the Paris Agreement and, also, give comparisons between the Kyoto and Paris designs to explain their differences, see Voigt (2014b), Strand (2017) and Harstad (2018).

IV.3 Barriers and opportunities to transformation

Behavioural economics

As reflected above, game-theoretical models tend to provide little optimism into the analysis of how countries can manage to coordinate for a shared gain. Negotiators and governmental representatives are humans, and recent literature on negotiations have nuanced the predictions from game-theoretical models by integrating novel findings from behavioural economics. For instance, Nyborg (2018a) has introduced so-called reciprocal preferences, i.e. the desire of humans to repay mean intentions by mean actions and kind intentions by kind actions, in a setting of international climate negotiations. A result is that a grand or majority coalition may be stable. Agreements like the Paris Agreement, in which countries pledge to abate voluntarily with no external enforcement, could conceivably be successful.

Our results shed light on several conditions that favour collaboration. For instance, when individuals can choose to join groups pre-committed to charity, such groups seem better able to sustain cooperation. The groups attract a greater number of more generous individuals, triggering generous responses by conditional co-operators, Hauge et al. (2019). More generally, social norms are found to complement more formal institutions in enforcing collectively desirable outcomes, see Nyborg et al. (2016) and Nyborg (2018b). People can be more willing to choose a behaviour the more widespread it is, and tipping points exist, where vicious cycles can turn into virtuous ones. Social sanctioning can create such tipping points, as can the occurrence of so-called conditional cooperation — an often observed willingness to cooperate more when others cooperate more. It is a precondition that the behaviour of others is observable. The role of policy could be to increase the visibility of behaviour that signal and form more climate-friendly norms.

The empirical analysis of behavioural economics is largely based on lab experiments of individuals, and CREE research has provided significant contributions, see Braaten (2014a; 2014b), Czajkowski et al. (2015), Hauge (2014; 2015; 2016), and Hauge et al. (2015). However, a possible concern with insights from lab experiments is whether this insight based on individual making decisions can be generalised to decisions made by firms and countries in global issues such as climate negotiations. CREE has contributed to a strand of literature within behavioural economics studying whether decisions made on behalf of others differ compared to decision made on own behalf. This is relevant for international climate policy negotiations, where negotiators represent their governments, see Hauge and Røgeberg (2015). Interestingly, we find a difference between men and women: women make less self-interested choices as representatives compared to as individuals, while no such difference was found for men.

Moral aspects of climate action

Related to social norms are moral norms and moral obligations. One question that is often raised in case of climate actions of individuals, countries, and regions, is whether there is a moral obligation for action even if the contribution might be small and of little practical significance. Fairness and equity can be reasons for expecting that capable individuals, for example rich countries like Norway, make disproportionally large contributions to global emission cuts. Several works from CREE address the potential trade-off between equity and efficiency and have suggestions to how undesired distributional impacts, both across generations and countries, can be compensated, see Kverndokk et al. (2014), Isaac and Piacquadio (2015), Kverndokk (2018) and Hoel et al. (2019). We have also studied what types of instruments and policy designs that can be perceived as fair, see Kverndokk (2012), Greaker et al. (2013), and Piacquadio (2017).

8. International cooperation

The main value added to CREE from international cooperation is access to a wider network with competence that complements the expertise of the CREE researchers.

The international cooperation in CREE consists of five factors. First, we had an international research partner, Tilburg Sustainability Centre (TSC). This centre has high competence in the interrelationships between technological change, economic growth and sustainability, as well as in theoretical analyses of environmental economic instruments. This expertise complements CREE researchers, some of whom have theory expertise in other areas, while others have expertise in more applied methods. As an example of the successful collaboration coming out of this complementarity, the CREE expertise on numerical modelling was combined with the TSC expertise on theory studies of emission trading. This led to a joint study of the new regulatory rules in the EU-ETS.

Second, the centre had international research affiliates. Each of these complemented the competence of the Norwegian CREE researchers:

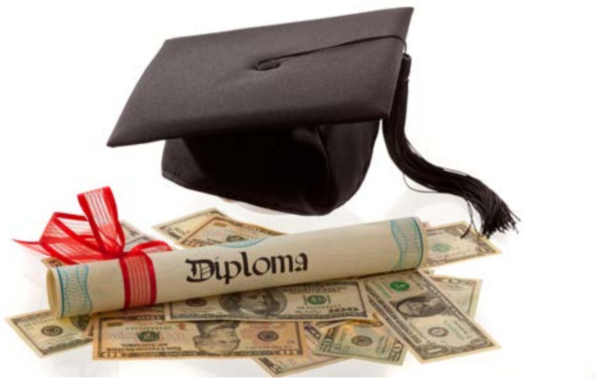
- Professor Fridrik Baldursson, Reykjavik University (Stochasticity and the electricity market)
- Professor Claude Crampes, University of Toulouse (Competition in energy markets)
- Dr. ing. Markus Blesl, University of Stuttgart (Storage technologies)
- Professor Claudie Boiteau, Director of the Master programme Law and Market Regulation, Université Paris-Dauphine (Electricity markets and law).
- Professor Stef Proost at Leuven University (Transport economics)
- Professor Böhringer, University of Oldenburg (Computable general equilibrium models).

The duration of CREE made it possible to undertake research projects running over several years that were finalized with international publications.

Third, all international research affiliates have always been invited to the annual CREE workshops, along with other international researchers in the field of environmentally friendly energy, to present suitable papers.

Fourth, CREE has participated in the EU funded project ENTRACTE under the 7th Framework Progamme (Project No. 308481). CREE researchers did research on energy efficiency policies, renewable energy supply, and efficiency of policy instruments.

Finally, there has been some exchange of researchers. Dr. Mads Greaker spent time in Tilburg, working on a joint research paper. Furthermore, PhD student Frikk Nesje intended to visit Tilburg University for one year. Nesje's plan was to spend time with Professor Reyer Gerlagh and other theorists to further his game theoretic studies of intergenerational decision making. Although there was interest from Tilburg and also available funding, the funding requirement was that Frikk Nesje would need to register as a dual PhD student at Tilburg University. The University of Oslo did not agree to this proposal, due to the imposed administrative burden of negotiating such an agreement.



Illustrasjonsfoto: Colourbox.no

9. Training of researchers

The CREE research partner, Department of Economics at the University of Oslo, organizes regular PhD and Master courses, including classes related to environmentally friendly energy; this topic is covered in courses in energy economics, electricity economics, resource economics, environmental economics and climate change economics.

CREE organized one PhD class on integrated assessment models jointly with MILEN (in 2013), the University of Oslo’s (former) interfaculty research network on environmental change and sustainable energy. Several CREE researchers lectured. CREE researchers have also given PhD or Master lectures related to environmentally friendly energy, both in Norway (organized, for example, by the FME research school NorRen, and also by UiO Energy), and internationally (organized by the EAERE-FEEM summer school in Venice).

CREE has offered Master Thesis scholarships to master students writing their Master thesis within environmentally friendly energy. As a rule of thumb, each year three students have received scholarship. These have been integrated into CREE projects, working jointly with

CREE researchers, and they have been provided office space in a CREE institution. In total, 22 students have submitted their master thesis after receiving this scholarship, see Appendix 2a for names and title of theses.

Finally, one CREE researcher has three times taught in a multidisciplinary energy course offered by UiO Energy, and also written a memo on energy markets for master students taking the class.

CREE has recruited well qualified PhD students and a post doc. through joint (international) announcements with Department of Economics at the University of Oslo and Statistics. Below, two CREE PhD students, and one CREE post doc, share their experience from being part of the CREE centre.

Alice Ciccone (Italy), former CREE PhD student:

When I started on my PhD in 2011, CREE was the most suitable and interesting environmental economics research centre. CREE managed to unite many different Norwegian and international researchers to create a lively research community focusing on a variety of relevant economic problems and using a large range of methodologies. This was the main reason for why I thrived as a CREE member during my PhD period. I had the opportunity to extend my research network, and to participate in conferences and summer schools where I discovered new approaches to problems that really helped me writing the thesis and also shaped my interests as a researcher. Moreover, I really enjoyed the internal activities such as the annual CREE workshop. This is because junior researchers like me had the opportunity to present work in progress and get important feedback from more senior and experienced researchers in the field. These inputs helped me a lot in writing my dissertation. I am now working as a senior researcher at the Norwegian Centre for Transport Research (TØI).

Marit Klemetsen (Norway), former CREE PhD student:

My PhD thesis was on the effects of government environmental regulations and R&D funding on Norwegian firms' environmental behavior. The CREE affiliation was particularly important to me as my supervisors were not working on environmental or climate topics (they worked on topics as industrial organization and innovation and had insight in applied micro econometrics). CREE significantly broadened the opportunity for me to learn about the topic from senior researchers. I wanted to investigate the development of firms' polluting emissions and also innovation, as innovation is decisive to achieve sufficient emission reductions. As CREE covered both areas, I had many opportunities to learn and get feedback on my work. Through CREE, I was part of a strong academic environment.

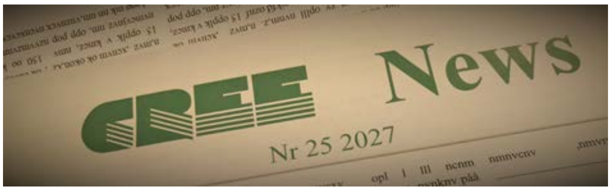
I found it very stimulating to be a PhD student at CREE. It gave me the opportunity to work with and present my work regularly to some of the leading scholars in the field. As the dissertation was on Norwegian firms' environmental behavior, both with regards to emissions and innovation, my work fit into several of the CREE WPs. I benefited a lot from working with other CREE researchers, like Brita Bye and Knut Einar Rosendahl. Through Rosendahl, I got the possibility to co-supervise two master students on the econometric part of their theses. I learned a lot from attending and presenting at workshops and conferences, and to relevant actors such as the Norwegian Environmental Agency and several ministries.

During the first few years after the PhD, I used my empirical data knowledge as a government analyst, working for agencies such as the Tax Authority and a multi-agency analytics and intelligence center. This provided me with a broader knowledge on political and bureaucratic decision-making, which is crucial to make the research relevant.

Today, I have a permanent position as a senior researcher at CICERO center for international climate research, and I work on several projects, e.g. related to climate attitudes and behavior, climate adaptation in Norwegian municipalities, and climate finance. I use the knowledge attained during my PhD on a daily basis.

Daniel Spiro (Sweden), former CREE post.doc:
I spent four years funded by CREE and enjoyed this fantastic research environment. I must say that these years were formative for my research career. CREE and the Oslo area is probably the leading research centre in Europe when it comes to environmental economics and is one of the best in the world. Being part of it was indispensable as I got feedback and ideas for my own work. I also got the opportunity to listen to the presentations of other researchers, and to expand my network. The members of the network were always generous with their time and interested in listening. One very valuable aspect was the atmosphere of a joint goal of pushing the research frontier rather than competing against your peers. This paved the way for great research, and also for a very pleasant work environment. Currently, I am an assistant professor at Uppsala University in Sweden.

Employment of PhD-candidates (number)							
By centre company	By other companies	By public organisations	By university	By research institute	Outside Norway	Other	Total
1			2	3	1		7



10. Communication / Popular dissemination of knowledge

In CREE, communication to the academic audience is mainly organized through three channels: publication of working papers available at the CREE web site; presentation at international research conferences and seminars; and publication of academic papers in peer review journals, see point 6 in this report.

The channels used for dissemination of knowledge outside the research communities have been:

- The CREE web site https://www.cree.uio.no/. Substantial resources were used to develop and upgrade this site. It provides information on the structure of CREE: all CREE projects with project description, project members, funding and associated papers of various types; a complete listing of papers of various types; outreach activities like CREE events and presentations for users and academic peers.
- When posting a new CREE working paper at the CREE web site, a non-technical summary in Norwegian is provided.
- CREE News Letter is mailed to CREE user partners at least three times a year. It provides information on upcoming CREE events, a short description of recent CREE working papers, and typically in-depth information about one or two CREE publications.
- In 2014, a Royal Commission was formed to develop and describe a green tax reform to help the Government reach local, national and international environmental targets (NOU 2015:15 Sett pris på miljøet—Rapport fra grønn skattekommisjon). As many as three members of Commission were key CREE researchers, while three other CREE researchers contributed to a sub-report summarizing the research on policies for promoting the development and uptake of green technologies. This work was highlighted as one of four good practice cases for societal impact in economics by the RCN commissioned evaluation of social sciences in 2018 (SAMEVAL).
- The contribution from the CREE researchers drew on the group's general competence in a number of subfields within economics (like public economics, environmental economics, climate economics, R&D) as well as their own research.
- CREE researchers have contributed to a number of other reports from various commissions, see point 13 below.
- CREE researchers have been encouraged (through an internal incentive mechanism) to be visible with policy-oriented results from their CREE projects in newspapers, TV and radio: CREE in the media (https://www.cree.uio.no/outreach/news/in-the-news/). As a rough rule of thumb, CREE was in the media every second week.

11. Effects of centre for the host institution and research partners

Effects of serving as the host institution for CREE

Strategy:

CREE has been an essential part of the research strategy of the Frisch Centre, a non-profit research foundation established by the Economics Department at the University of Oslo. The aims of the Frisch Centre is defined in its statutes to be a centre for research in economics, serve basic research, strengthen applied research and to contribute to the education of new researchers at the University of Oslo (UiO). The strategic aims are constrained by the need for financing: the majority of the Frisch Centre's funding comes from competitive grants from the Research Council of Norway (RCN).

CREE has enabled the Frisch Centre to work with a longer time perspective and a wider scientific field than the shorter RCN project grants. CREE has enabled the Frisch Centre to maintain and expand the group of highly competent researchers within the field of environmental and energy economics, one of the three main pillars of research at the Frisch Centre along with labour economics and public economics. The scientific goal of the group is to do high-quality, theoretical and empirical research on topics of relevance to energy, natural resources, and climate policy, and to have methods and results communicated to and assessed by the broader scientific community through publication in high-quality, peer-reviewed scientific journals. CREE has allowed the continued development of the European energy market model LIBEMOD that is operated jointly with Statistics Norway, work which is not easily financed within other projects with a narrower focus. The long-term funding through CREE has provided a basis for developing research ideas that have resulted in excellent publications in the international scientific literature.

Network:

The Frisch Centre collaborates in several formal research networks in Norway. The CREE Centre formalizes collaboration with research groups in Statistics Norway, the Department of Economics (UiO) and the Tilburg Sustainability Center, and also formalizes collaboration on environmental/energy research with individual researchers from other disciplines (e.g., law) and countries (e.g., USA). These networks are now well established and have resulted in a number of joint research projects with separate funding within the thematic framework of CREE. The Frisch Centre aims at continuing this cooperation in future research projects and using internal funding to sustain the CREE network with common seminars, web-pages and dissemination activities.

CREE has also strengthened the informal networks with academics in the field across the world, by allowing participation in international conferences, the invitation of guests and the paid or unpaid collaboration with individual researchers from other institutions.

Collaboration with non-academic partners has been a core consideration in CREE. CREE has a number of user partners, involved in and served by the research activities. Frisch Centre researchers have been involved in extensive communication with users, regularly holding presentations for relevant government groups and units. This activity also requires an interest and demand from the user groups, and this demand has varied over time, but CREE has provided a platform for dialog and channeling questions and research interest to and from users both in the public and private sector. The user contacts have resulted in cooperation on new research proposals with industry and government involvement.

Quality in education:
CREE has provided scholarships for master students and has thus encouraged master students to write their theses on themes in environmental and energy economics under the supervision of Frisch Centre and other CREE researchers. The Frisch Centre is not an educational establishment, but our staff has contributed to the quality of education in the field by holding formal courses at the University of Oslo and other institutions, both at doctoral and lower levels.

Recruitment of students and researchers:
The Frisch Centre is by intention a small institution, but CREE has consolidated our standing and reputation as a major research group within the field of environmental and energy economics. Thus CREE has contributed to the brand building of the Frisch Centre. When last hiring researchers we had a very strong list of applicants including several highly successful economists within the field, and succeeded in employing a very promising and competent young researcher with a recent PhD within empirical environmental economics.

Effects of being a CREE research partner

Research.
The CREE center has contributed to substantial research in the fields of energy, climate change and environmental economics. The centre has also triggered interdisciplinary research, mainly as cooperation between i) economists and social anthropologists, and ii) economists and technology experts, but also with contributions from political science, law and psychology to complement the economic perspective. CREE funding has been important to ensure that working papers have been developed into international publications; this may require a substantial amount of work after the working paper was finalized.

Within centre cooperation and network.
CREE has triggered substantial collaborations between the three Norwegian research partners, and also led to more contact and cooperation with the international research partner. This is reflected in our reference list as numerous publications with authors from more than one research partner. CREE has also made it possible for the Norwegian research partners to build, maintain and extend domestic and international networks, for example, by having international experts affiliated to the centre. This has led to substantial cooperation and materialized in several international publications.

Numerical model development.
In the first period of the CREE center, the work package "The Next Generation of Numerical Models" provided funding to a comprehensive extension and updating of the numerical energy market model LIBEMOD. Furthermore, it made it possible for CREE to establish a new family of numerical models, suited for analyzing energy and environmental policies both for the Norwegian economy and for the global economy – the SNOW models. This modelling project included a collaboration between several institutions that expanded the CREE network, thereby making it possible for Statistics Norway to take part in a Stanford Energy Model Forum study. The SNOW model for Norway is now the main model for climate analyses and long-term forecasting used by the Norwegian Ministry of Finance and other ministries.

Cooperation with other FME-S centers.
The CREE center has also opened the opportunity for a community among the three FME-S centers – CENSES, CICEP and CREE. There has been collaboration with respect to research applications, user seminars, and modelling.

Education and recruitment.
CREE has offered Master scholarships which have led to a number of Master Theses being written as part of the activity of the centre, with CREE researchers as supervisors. Some of these students have continued as PhD students. Also, there has been CREE funding of PhD students and one post doc.

User partners.
During the CREE period, there has been substantially more interactions with user partners than what was typical prior to CREE. This has had powerful implications with respect to dissemination of research output; new ideas for research questions to explore; and joint research applications.

Research applications.
CREE has triggered a number of research applications with participation from the research partners, subcontractors and user partners. In general, the success rate has been good. Hence, CREE has obtained additional funding for research activities (WINDLAND, ELECTRANS, SMARTH PATH, PLATON) related to the core topics in the centre. Some CREE researchers also participated in an EU Horizon 2020 application that obtained funding.

To sum up, through generous funding from the RCN, CREE has been given the opportunity for long-term, high-quality, user and policy oriented research. Our effort has clearly enhanced cooperation between the research partners, which has materialized in numerous publications in peer-review international journals, in particular, several publications in top field journals, top general economics journal and also publications in multidisciplinary journals.

12. Effects of centre for the company partners, public partners and society at large

The CREE user partners have values like scientific-based decisions, promote sustainability, and facilitate green transition. These values are in line with the basic idea of CREE; to design and assess policy measures that facilitate and ease the transition to a low-emissions society. Also, the main objectives of the user partners are aligned with the research activities of CREE; improved knowledge on how to cut GHG emissions and obstacles to achieve emissions cuts, how to achieve more electrification, the role of consumer flexibility, and green R&D and growth.

a) Review of what is considered the most important effects

The CREE user partners are in general involved in a number of R&D activities, but typically these are outsourced to a number of R&D firms, for example, CREE. Hence, CREE has had a minor influence on the general R&D and innovation strategy of the user partners, but user partners have facilitated easy internal access to output from CREE R&D activities.

The feedback from the user partners suggest that CREE has been important because of:

- Improved general understanding of basic issues related to environmentally friendly energy. In particular, improved understanding of challenges facing user partners aiming at reaching specific policy targets.
- Significantly more dialogue with researchers and thereby stimulated interest in reading research papers as well as learning about recent developments in the field.
- Significantly more dialogue with other user partners in the field of environmentally friendly energy
- Enhanced opportunity to detailed professional discussions with CREE researchers on topics related to ongoing projects at the user partners.

b) Success stories

I CREE Hot Line

CREE offers CREE Hot Line to it user partners. These are informal meetings where the user can discuss methodological and policy issues with CREE researchers. In a Hot Line with the Norwegian Environment Agency in 2017, CREE researchers presented output from model runs of the European energy market model LIBEMOD for the development of non-ETS emissions in the EU. The meeting was followed up by multi-stage dialogue between the CREE researchers and the Norwegian Environment Agency, which resulted in more model runs and a CREE memo with updated and extended results on non-ETS emissions in the EU. The Norwegian Environment Agency used the results as inputs in their own report on flexible climate policy mechanisms in the EU, which was commissioned by the Ministry of Climate and Environment.

II CREE Dialogue Seminar

Once a year, CREE organizes a half-day seminar for its user partners on topics of mutual interest. In 2017, the topic was the social discount rate, which had been requested by several CREE user partners. Both CREE researchers and user partners gave presentations. Later, an article on the social discount rate was written by two CREE researchers. The paper was published in the journal Samfunnsøkonomen, and received significant interest among the CREE user partners.

III Model development

CREE has collaborated with the Ministry of Finance to develop an equilibrium model for the Norwegian economy (SNOW-No) that can be used for calculations in the next White Paper on Long-term Perspectives for the Norwegian Economy (Perspektivmeldingen). In accordance with the wishes of the Ministry of Finance, the model extensions include updating the dataset, expansion of the number of sectors, more detailed breakdown of taxes, as well as the inclusion of all greenhouse gases in the Kyoto Protocol. The model has been adapted so that the model user can control some parameters that are particularly relevant/interesting for the Ministry of Finance. Further adaptations makes it possible for the Ministry of Finance to simulate various configurations of climate policy (eg., a cap on emissions, carbon taxes and allowances). In addition, the model has become more user-friendly. Several courses and workshops on how to use the model has been arranged for the Ministry of Finance.

IV Model development — energy and climate policy

CREE has developed and updated a model for the study of energy and climate policy. The model combines the macro perspective of numerical equilibrium approaches with the technology knowledge of energy models. In this project CREE has collaborated with The Norwegian Environment Agency on data processing and with IFE (Institute for Energy Technology) on modelling.

c) Feedback from some active campany or public partners

NVE (The Norwegian Water Resources and Energy Directorate)

NVE has used CREE as a platform for debate and exchange of economic methodologies, as well as a discussion partner for challenges facing an energy agency in a green transition period. NVE has participated in projects as well as in research proposals, although the latter ones did not obtain funding. For NVE, participation in CREE has been important as it enhances the agency's cooperation with social science research groups, and also provides access to user partner events to discuss research results that are applicable in the ongoing work at NVE.

NVE monitors relevant research. Once NVE finds results that have powerful implications for its daily operations, their own models and approaches are adjusted to take recent developments into account. One example is the CREE analysis of the rebound effect of heat pumps, which joint with internal analyses at NVE triggered an assessment of the TIMES Norway model with respect to the possibilities to incorporate behavioural effects that come in addition to existing techno-economic factors.

NVE has been active in participating in all types of CREE user partner events, in particular, in the dialogue seminars. We have benefited a lot from the professional discussions at these seminars. Also, NVE has had the pleasure to take advantage of the CREE Hot Line a few times. NVE appreciates the effort of CREE to offer tailor made presentations and synthesis memos on energy markets and household behavior.

For NVE, the greatest challenge with the CREE cooperation is all the administrative efforts necessary to follow up research projects funded by the Norwegian Research Council. NVE is involved in numerous projects that differ along several dimensions, and even the administrative terminology of the projects may differ. Frequently, the role of NVE is not clear; should we assist researchers or govern the project? Finally, NVE employees find that the time available for following up research projects may be a buffer; managing daily operations always has the highest priority. Therefore, each NVE employee should not be involved in too many projects.

MDIR (Norwegian Environmental Agency)

The objective of the Norwegian Environment Agency is to obtain a clean and diverse environment. Our primary tasks are to reduce greenhouse gas emissions, manage Norwegian nature, and prevent pollution.

We are a government agency under the Ministry of Climate and Environment. We implement and give advice on the development of climate and environmental policy. We are professionally independent with respect to decision making, advising, communication of knowledge and information dissemination.

One of our main values is to be knowledge based. Our decisions and advices to the Ministry are based on facts and knowledge. Thus, having access to high quality, state-of-the art knowledge and research is crucial.

We have participated as a user partner in CREE, and have been a board member in most of the project period.

For us, the main benefit of CREE has been the way the centre has constituted an arena for dialogue with highly qualified researchers within environmental economics, as well as with other user partners. Through our participation in the centre, we have gained access to relevant research, and have had research presented for us at the agency. More importantly, the user seminars have been a good arena for discussing methodological questions, such as the seminar on the discount rate. The CREE Hot Line, which we have used in three different cases, has also been useful, giving us the opportunity to discuss top-of-the-list topics with the CREE researchers.

GASSNOVA

Influence on R&D and Innovation strategy

Through participation in CREE, Gassnova has gained more insight into results from economic research, in particular, CREE research output. The understanding of the need for economic research on CCS has increased over time as it has become clearer that market barriers and other market failures have implied lower dissemination of technology than what is socially warranted. Insight from economic research into issues concerning the climate and energy use has enabled Gassnova to target its own activities on international market trends, which is important for the development of CCS. Indirectly, this has also contributed to Gassnova being able to give more robust advice to the Ministry of Petroleum and Energy on CCS issues and to make more robust assessments to applications submitted to CLIMIT.

Strengthened knowledge base

As a CREE user partner, Gassnova has gained a better knowledge on:

- Utilization of results from economic analyzes on public investment projects, including improved foundation for the choice of the discount rate
- CO2 pricing in different markets, and improved understanding of spillover-effects between markets
- How policies affect CO2 pricing and the uncertainty associated with future CO2 prices
- How various policy instruments, for example, supply-side policy, may influence CCS decisions
- Specific considerations on ambitious climate political measures, including the interrelationship between CCS and carbon leakage
- Insight into how climate negotiations are taking place, and thus a greater opportunity to interpret possible outcomes and effects related to adoption of CCS.

Improved access to competent personnel and research institutions

Through participation in CREE, Gassnova has gained easy access to research and academic resources that would otherwise have been less accessible.

13. Effects of centre for the overarching goal of the FME-programme

As stated above, the main vision of CREE was to generate knowledge that can contribute to a cost-effective and sustainable exploitation of Norwegian and international energy resources by industry and governments, as well as an effective and fair climate and energy policy, both nationally and internationally. Hence, the purpose of our research activities has been to improve the knowledge base on how to reach energy, climate and environmental policy targets.

CREE has covered all Norwegian energy-related GHG emissions sources, and CREE has also examined how to promote renewables as well as explored, within a multidisciplinary framework, costs and benefits of initiatives aiming at improving energy efficiency. These tasks are reflected in the titles of our four flagships:

i) ***Radical emissions reductions in ETS sectors.*** This flagship examines driving forces of emission activities in ETS sectors, and choice of regulatory instruments in ETS sectors, including carbon capture and storage (CCS).
ii) ***Environmentally friendly transport.*** Identification, analyses and recommendation of sustainable emission reduction strategies for the transport sector.
iii) ***Green innovations and utilization of smart technologies.*** How policies can motivate and incentivize research, development and diffusion of environmentally friendly technologies.
iv) ***Towards the low-emissions society.*** Pathways for nations, regions and the world towards the low-emission society.

CREE has contributed to design of instruments and regulations to reach energy, climate and environmental policy targets, as well as identifying obstacles on the way towards the low-emission society. The Centre has explored standard measures, like incentivised policy measures, as well as alternative measures, for example, supply-side climate policy measures.

While the main objective has been to improve the general knowledge base for policy design, CREE researchers have also contributed to reports from appointed commissions, and provided input to ministry publications. The most important contributions are listed below:

- ***Green Tax Commission.*** Six CREE researchers contributed to the Royal Commission aiming at designing a green tax reform to help the Government reach local, national and international environmental targets (NOU 2015:15 Sett pris på miljøet—Rapport fra grønn skattekommisjon), see point 10 in this report. The contribution from the CREE researchers drew on the group's general competence in a number of subfields within economics, as well as their CREE research.

The Commission recommended specific and broadranging changes to the tax structure and regulatory system, and their report was widely discussed in Norway, forming an important basis and common ground for later political discussions in the Parliament. A keyword search in print newspapers finds some 260 references to the Commission in 2015 and a further 295 in 2016, documenting how the Commission's report became widely discussed and accepted as an important reference in the ongoing debate about environmental policy and a green transition. In the recommendations of the Parliament's Financial Committee for 2017, the Green Tax Commission is referenced some 15 times. The core principles of the Commission received broad support, and representatives from different political parties emphasized their acceptance of the Commission's report (though frequently differing in which of the recommendations they emphasized).

- ***Supply side climate policy.*** CREE researchers raised the debate on whether a petroleum extraction country like Norway should use a combination of demand and supply side measures in its climate policy, that is, whether cuts in oil and natural gas extraction should be part of Norway's measures to reduce GHG emissions. This triggered a heated debate, which is still ongoing. Several CREE papers were written on suppy side measures, two examples are i) Fæhn, T, C. Hagem, L. Lindholt, S. Mæland, and K.-E. Rosendahl (2017): Climate policies in a fossil fuel producing country, Demand versus supply side policies, Energy Journal, 38 (1), 77-102, and ii) Asheim. G. B., T. Fæhn, K. Nyborg, M. Greaker, C. Hagem, B. Harstad, M. O. Hoel, D. Lund, K. E. Rosendahl (2019): The case for a supply-side climate treaty, Science 365(6451), 325-327. The latter paper inspired a party at Stortinget to suggest that Norway takes the initiative to establish an international agreement to lower oil and natural gas extraction (Representantforslag 26S I 2019, December 12, 2019).

- ***Klimakur.*** Right before the establishment of CREE, researchers at Statistics Norway, who later became CREE researchers, contributed to the report Klimakur 2020. The same group has since 2019 been working on their contribution to Klimakur 2030 (their part of the report will be delivered before June 2020). It will build on numerical models that have been developed and updated during the CREE period.

- ***Various deliveries to Norwegian ministry publications.*** CREE researchers have contributed to
    - Stortingsmelding 25 (2015-2016) Kraft til endring – Energipolitkken mot 2030. Model runs of the computable general equilibrium model MSG.
    - Stortingsmelding 41 (2016-2017) Klimastrategi for 2030 – norsk omstilling i europeisk samarbeid. Model runs based on an energy market model (LIBEMOD) and a computable general equilibrium model (SNOW).

- Perspektivmdelingen 2020. This is work in progess that will build on models runs of two computable general equilibrium models (MSG and SNOW).

- ***Norwegian expert groups.*** One CREE researcher was member of the "Ekspertgruppen for Oslo kommunes klimabudsjett (2019). One CREE researcher is currently member of "Teknisk beregningsutvalg for klima", whereas another CREE researcher is member of "Teknisk beregningsutvalg for utslipp fra jordbruket".

- ***IPCC.*** One CREE researcher has twice served in the IPCC secretariat. For the 5th assessment report, he was Review Editor for working group III (Mitigation). For the 6th assessment report (work started in spring 2019), he is Lead Author with the objective to write the Introduction to the report from working group III.

14. Analysis of the role of the centre

i) "Environmentally friendly energy" is a comprehensive field in several academic disciplines. In economics, the core discipline in CREE, it builds on both micro and macro economics, and it is related to a substantial part of energy economics, environmental economics, resource economics and climate economics. The economics of environmentally friendly energy is an applied field with applied theory contributions as well as empirical contributions. Most papers in the field are either policy oriented or provide a foundation for future policy-oriented contributions.

At the start of the period of CREE, a substantial part of the economics of environmentally friendly energy was related to policy questions that were under academic and public debate around 2011. For example, how to design instruments to minimize the carbon leakage, how to spur environmentally friendly R&D, the role of climate-friendly electricity, and development and use of large-scale numerical models to simulate the impact of alternative environmentally friendly policies, both at the sectoral lever, in particular, the electricity market, and for the entire economy of a country or a region of countries.

ii) After 2011, the EU has announced ambitious energy and climate targets and most countries in the world have ratified the Paris agreement. These events have had impact on the research agenda of CREE as well as on the general field. There is now much attention on predictions of future GHG emissions from various countries, whereas carbon leakage is not an important topic any longer. Furthermore, with the EU target of lowering carbon emissions in the electricity generation sector by 95 percent by 2050, there is more focus on intermittent power sources and storage technologies, as well as consumer flexibility and the value of lost load. These trends are also reflected in the CREE project portfolio.

iii) Most of the CREE user partners take a general interest in the economics of environmentally friendly energy. Through CREE user activities, our users have been given an opportunity to follow the general development in the field as well as been invited to discuss output from state-of-the-art CREE projects. Our user partners do not have a substantial internal R&D department, and hence to be updated on the development in the field they appreciate user activities like the ones CREE have organized.

iv) It is beyond the scope of this report to assess the role of CREE in the recent development of the field environmentally friendly energy, but the high number of published peer-reviewed articles from CREE, as well as the international awards to CREE researchers, suggest that CREE has contributed to the field.

Case: Flagship III

To take one example of how a specific field has evolved and the associated CREE research activities, we focus on flagship III. Here, the main focus has been on micro economic behavioral analysis of the diffusion of environmentally friendly and smart technologies in households and firms. The analysis in this flagship have focused on getting a more in-depth understanding of energy behavior, how it is affected by external changes such as energy efficiency measures or smart technologies, and how this in turn affect energy consumption. An extensive collaboration between economists and social anthropologists have been conducted to get a deeper understanding of household preferences and energy practices.

At the start of the center period, very little empirical work had been done on these topics in the economic literature at the micro level. There was a substantial literature, also on Norwegian data, on the technical savings potential of various energy savings measures. However, very few studies discussed how households and firms would use these new devises in conjunction with their existing equipment, and how this would change their behavior and thus their energy consumption. Both types of studies are necessary to design an efficient policy based on empirical knowledge, as studies of the technical savings potential, although very important, only give a part of the story, namely the technical aspects of the equipment. As economists, we expected the behavioral changes (rebound effects) to increase with the technical energy savings potential. Thus, we expected to find that the most efficient energy saving devices would generate the largest rebound effects. This was exactly what we found in our research.

At the end of the CREE period, much of the existing literature in this field is still focused on the technical energy savings potential. There are some analyses done focusing on behavior and rebound effects, both in micro (as in flagship III) and secondary rebound effects through the markets. However, there is still a potential for new empirical behavioral studies, in particular with respect to the dissemination of new technologies with a potentially big impact on society, such as electric vehicles.

15. Future prospects

Two of the CREE research partners –the Frisch Centre (the CREE host institution) and the research department at Statistics Norway – are interested in a continuation of the CREE network. The main activities may be the following:

- Joint research proposals with participation from CREE user partners as well as other CREE research partners/subcontractors
- Regular CREE research seminars
- An annual CREE research work shop, organized jointly with ongoing research projects at the Frisch Centre and Statistics Norway
- Continuation of the CREE working paper series
- Continuation of the CREE web site (but content has to reflect that CREE mainly offers network activities).

The main challenge of the plan is funding. As of March 2020, the strategy is that the research work shop is funded by ongoing research projects within the field of environmentally friendly energy, whereas other activities are funded by the Frisch Centre and Statistics Norway. In addition, in Mai we will apply for network funding from the Norwegian Research Council as the core of the CREE researchers is almost identical to the Energy and Environmental Economics group of the Frisch Centre that obtained grade 4 under the SAMVAL evaluation.

16. Conclusions

CREE had powerful impact along a number of dimensions:

- It has stimulated joint research activities between the research partners. Prior to CREE, there was some cooperation between the groups, but this increased significantly once CREE was established. The funding of the centre paved the way for joint long-run projects and associated papers. In particular, it made it possible for substantial development of numerical models, an activity that was given first priority of the expert panel that assessed the application from CREE.
- The stated purpose of the social science research centers for environmentally friendly energy, and also the midterm evaluation of CREE, triggered more interdisciplinary research and also more projects exploring other topics than what has been typical by academic economists.
- The centre building activities (seminars, research workshops, summer and Christmas parties, CREE lunches) also had impact on research cooperation. However, the participation on the more social-oriented activities tended to decrease over time.

- The annual requirement of submitting work plans had a disciplinary effect on those in charge of work packages and flagships, thereby pushing research groups to finish their papers in time. Also, for the management group of CREE, it increased the transparency of the centre, thereby enhancing cost control.

- The stated purpose of the social science research centers for environmentally friendly energy, and also the midterm evaluation of CREE, triggered more user-oriented activities and also more participation of users on research proposals. Our experience is, however, that it is hard to get user partners involved in projects, even if the projects are aligned with the R&D activities of the user partners, see Section 12c) on NVE as an example. Typically, time spent on CREE activities is squeezed if key activities of the employer require more time. This might be solved if the employer allows for commitment of personal involved in CREE activities.

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