Industrial Ecology Programme

Annual Report 2011

NTNU
Norwegian University of
Science and Technology

Programme director Edgar Hertwich
edgar.hertwich@ntnu.no

What is Industrial Ecology?

The question was posed by a member of the external review committee charged to evaluate energy-related research at the faculty. "Ecology is the scientific study of the relations that living organisms have with respect to each other and their natural environment," the committee member quoted Wikipedia, "but how does industry fit in?" I have to say that I was taken by surprise – somebody deemed by the faculty to be competent to assess our research must know about the field he assesses. While misplaced in a research assessment, it is nonetheless a question that is relevant to pose, as our students are also frequently confronted with it. And – while short, reliant on established terms, and appropriately indicating that the field is about industry and the natural environment – the term *Industrial Ecology* is also prone to be misunderstood.

Unlike *population ecology* or *freshwater ecology*, industrial ecology is commonly not seen as a sub-discipline of ecology. Its study does not primarily address living organisms, even though, of course, ecology also deals with inanimate variables like the pH and oxygen content of freshwaters and industrial ecology also addresses living organisms as resources, decision makers, and affected end-points. Industrial ecology was initially used as a metaphor, comparing the cycling of important industrial materials such as steel, aluminium or platinum in *industrial ecosystems*, with that of carbon, nitrogen and phosphorus in nature. Of the five research objectives of ecology listed in Wikipedia's definition of ecology, "the movement of energy and material through living communities" also closely describes the interest of industrial ecology, with a focus on those living communities formed by humans and their domesticated plants and animals. While those industrial ecologists occupied with assessing the emissions of industrial products, the flows and stocks of metals in society or the organization of industrial waste exchanges may think of industrial *ecology* as a metaphor, I would argue that in fact, industrial ecology and ecology are much more closely linked than by the analogy of material flows or the dynamics of complex systems.

- One of the key research subjects in ecology is the "grand geochemical cycles", which describe the movement of water, carbon, nitrogen, phosphorus and a great number of other elements or chemicals important for life on earth through both living organisms and the non-living environment. Today, these biogeochemical cycles cannot be understood without understanding the flow of these elements or chemicals through human-created systems, and it is the study of those flows that is the domain of industrial ecology.

- One of the most successful research foci in industrial ecology has been the study of the social metabolism, societies' use of various types of energy and materials both through historical periods and in different geographical and developmental contexts. This body of work has shown how the utilization of fossil fuels enabled societies to overcome an otherwise tight coupling to local biomass production both through fossil-fuel enhanced agricultural production and through transportation. The resulting increasing distance between us and our use of natural resources may also explain why we suddenly see human systems as being separate from local ecosystems. On the global level, however, we need to recognize that we still depend on natural ecosystems as ever before.

- Industrial ecology increasingly addresses biological resources when working on food and bioenergy and hence needs to understand the conditions of biological production. For industrial ecology, better understanding the impacts caused by the environmental pressures we quantify in our analysis of industrial systems and designing these industrial systems so that they are within the *planetary* boundaries requires a collaboration with ecologists. Similarly, ecologists recognize the need to better understand human systems, as they increasingly acknowledge that we live in the *anthropocene*, the geological age fundamentally shaped by the presence of humans in terms of climate, nutrient availability, land cover and river flow and many other environmental variables.

In practical terms, one can foresee an increasing collaboration between industrial ecologists and ecologists in understanding and working for the potential co-evolution of human and natural systems onto a mutually more beneficial pathway of development; addressing among other things anthro-biogeochemical cycles and habitat change. As the environment of non-living organisms becomes increasingly less natural and, intentionally or not, shaped by humans, there is an argument that natural ecology and industrial ecology should not continue as separate disciplines, but rather become one. "Industrial ecology is the scientific study of the relations that human systems have with respect to other living organisms and their natural environment," may be the future Wikipedia definition, specifying further, "with a focus on understanding the material interaction of human and natural systems and the consequences of this interaction for both."

PEOPLE NEWS

Professor Anders Hammer Strømman was honored with the Laudise Medal of the International Society for Industrial Ecology. This young researcher prize recognizes excellent research contributions to the field of industrial ecology and is awarded every other year. The ISIE awards committee underlined the contributions of Strømman in the areas of input-output modeling, method development in hybrid life-cycle assessment, and life-cycle assessment of bioenergy. Congratulations to Anders!

IndEcol says goodbye to visiting professor **Yaushi Kondo**. Yasushi and his wife stayed in Trondheim for two years. During the 19th International Input-Output Conference in June 2011, the Sir Richard Stone prize was awarded to Yasushi Kondo + co-authors for their paper, Improving the completeness of product carbon footprints using a global link input-output model.

PostDoc **Karin Veltman** won a Marie Curie Intra-European Fellowship with a research project addressing the prediction of the concentration of toxic effects of novel chemicals in the target tissue of species. This work is to enhance ecological risk assessment and to reduce the number of animal tests required to assure the acceptability of chemical use and emissions. This research will be conducted at Radboud University Nijmegen, the Netherlands, where Karin received her PhD. At NTNU, Karin worked on the risk assessment of CCS, oil drilling, and developed ideas for the assessment of marine f ecological effects in LCA.

Thomas Gibon has joined the Industrial Ecology programme first as researcher and since December 2011 as PhD student. Thomas works on a project called Environmental Sustainability of Low-Carbon Energy Technologies, financed by the Research Council of Norway. Thomas has a bachelor in engineering from the École Centrale Paris and a Master in Industrial Ecology from NTNU. He has worked 1.5 years as a junior LCA consultant at Bio Intelligence Services in Paris.

Former PhD student **Thomas Martinsen** has joined the faculty of the Norwegian University of Life Sciences in Ås, where he teaches efficient energy and resource utilization and Energy systems and Technologies. In addition, he continues his research and consulting work on energy system modeling.

Our former PostDoc, **Professor Xiangping Zhang** of the Chinese Academy of Sciences, is back at NTNU and continues to work on CO2 capture under the BigCCS research centre.

Paul C. Stern joined the department of Psychology as an adjunct Professor in the summer of 2011. He is an outstanding internationally renowned psychologist in the field of global environmental change and sustainable consumption.
Sunita Prugsamatz got a 4 year Post-Doc position at the department of Psychology

Professor Ellen Matthies at the department of Psychology left her position in November 2011, and has now a new job in Magdeburg, Germany.

The Department of Hydraulic & Environmental Engineering hired two new people: **Amund Nordli Løvik**: PhD student; background in material science; is studying alloying element accumulation in aluminium.
Franciska Steinhoff: Postdoc; background in marine ecology; is studying wood use in Norway and phosphorus cycle in Baltic Sea basin.

In September 2011, **Dr. Martina Keitsch,** a former IndEcol postdoc, joined IPD as an associate professor.

Professor Gunnar Fermann at the Department of sociology and political science has been awarded a Fulbright Scholarship grant for 2012-13 researching "Energy Security and Foreign Policy: Case-studies in Strategic Leadership Comparing Norway and the United States"

Gunnar Fermann is accepted as Visiting Scholar to SCANCOR, Stanford University Fall 2012, and to The Norwegian Berkeley Center, University of California Berkeley, Spring 2013.

Industrial Ecology programme

IndEcol is a matrix organization coordinating teaching and research in industrial ecology at the Norwegian University of Science and Technology, NTNU. The programme was initiated in 1994 on suggestion of Norwegian industry. A comprehensive educational curriculum was launched in 1999 and turned into an international MSc programme in 2005. Faculty and PhD students affiliated with IndEcol also belong to disciplinary departments where they are employed. In 2011, 16 Msc degrees were awarded and 4 Master of Technology (MT) student completed a thesis at IndEcol. 15 new MSc students and 2 MT student were admitted. During 2011, 4 dissertations were successfully defended. 19 PhD students, 6 Post Docs and 4 Researchers were affiliated with IndEcol. 3 book chapters, 9 Accredited conference proceedings, 60 journal papers, and 1 IndEcol report were published.

Faculty Committee: Casper Boks, Helge Brattebø (MSc programme director), Gunnar Fermann, Annik Magerholm Fet, Edgar Hertwich (Programme director), Christian Klöckner, Daniel Müller, Anders H. Strømman.
Student representatives in 2011:
Blane Grann and Anna Karoline Petersen
PhD/PostDoc representative:
Guillaume Majeau-Bettez

NTNU's international MSc programme in Industrial Ecology

The international MSc programme in Industrial ecology (MSINDECOL) is NTNU's response to the need for candidates with an in-depth knowledge of industrial ecology theory, methods and applications. It is organized as an international master programme, with all activities (teaching, exercises, projects and thesis) in English, with the majority of students coming from abroad, and with a content that should reflect industrial ecology methods and applications in a global perspective. Not only are many of the present and future environmental problems of an international or global nature, but so are modern value chains, production systems, corporate strategies and ownership, and not to forget, much of the environmental policies.

On this background, MSINDECOL is recruiting students from various backgrounds. During the last years, about 20-25 applicants per year successfully entered the programme, with about two third coming from abroad, with the majority from Europe, Northern America and Asia, and with a bachelor's degree in Engineering, Natural Sciences, Management or Social Sciences. Hence, this is a very broad background, but our experience from many years of teaching is that students are highly motivated and very much open to pushing their boundaries across disciplines and cultures.

Along with a large number of young professors, post-doctoral researchers and ph.d. students, who all actively help facilitate a good learning environment, the outcomes turn out to be excellent. We are happy to observe that the majority of graduates from our programme successfully have entered exciting jobs with industry, governmental agencies, environmental consultants, as well as non-governmental organizations. Due to the fact that industrial ecology is a fairly young academic field, with a rapidly growing demand for methods and knowledge, we also see that many of our best graduates continue doing a ph.d., in Norway or abroad.

NTNU started teaching industrial ecology close to twenty years ago, in 1994. In 1998 we were the first university in the world to launch a masters programme in industrial ecology, and in 2001 the first one to launch a ph.d. programme in industrial ecology. Today we see a strong and growing interest for studying this field, all over the world, and the reason for this, we believe, is the need for scientifically based methods, knowledge and ideas on how to improve production-consumption systems. At MSINDECOL students can choose between two fields of specialization; a) Environmental Systems Analysis, and b) Environmental Politics and Management. The first specialization offers in-depth knowledge and skills in how to examine and verify, according to state-of-the-art methods, improved environmental impacts from systems at different levels (innovative product systems, biofuels, energy systems, waste management, urban water systems, building stocks, etc.). The cornerstone of such studies is skills in analytical methods such as material flow analysis, energy analysis, life cycle assessment, input-output analysis and scenario analysis. We are happy to observe that NTNU is recognized to be one of the leading universities world-wide in teaching and research within this field of specialization. The second specialization offers basic knowledge in environmental policy, environmental psychology, environmental management and industrial design processes. Departments in the Social Sciences and Technology Management cover most of these topics, and students who specialize in this area normally have a social science background from their bachelor's degree.

If you want to learn more about our programme, please consult the website: http://www.ntnu.edu/studies/msindecol

Contact person:
MSc Programme director/
Professor Helge Brattebø -
helge.brattebo@ntnu.no

Graduation class 2011

MASTER'S THESES 2011

Ocatvio Torres:	Life cycle assessment of a pumped storage power plant
Nevena Gajic:	Human dimensions in natural resource management for the Vosso wild salmon population -A systems thinking approach
Dina Margrethe Aspen:	Indicators for managing and communicating eco-efficiency in the maritime industry
Christine Birkeland:	Assessing the life cycle environmental impacts of wind power generation and power transmission in the North Sea
Kari Sørnes:	Heating and ventilation of a highly energy efficient residential buildings: Environmental assessment of technology alternatives
Ida Lund Segtnan:	Assessing the environmental costs and benefits of households electricity consumption management
Kristin Fjellheim:	An implementation of the World Trade Model with the GTAP database
Magnus Grinde:	Environmental assessment of scenarios for products and services based on forest resources in Norway
Marina Magerøy:	Communication of environmental impacts through environmental product declarations
Hilde Kristine Iglebæk:	The Norwegian Government Pension Fund Global (GPFG) and the exclusion principles
Jiayi Yin:	Carbon footprinting on carton & low carbon scenarios development
Martin H. Gallardo:	Life Cycle Assessment of a set of platform chemicals (phenol compounds, solvent, soft and hard plastic precursors) from fossil and biomass scenarios
Tobin Rist:	A Path to BIM-based LCA for Whole-buildings-Using Building Information Modeling (BIM) to automatically generate ILCD compliant Life Cycle Inventories
David Klar:	Intergenerational Equality and Sustainable Housing – New Applications for Ecological Economics
Gifty Serwaa Mensah:	Resource recovery from municipal solid waste in Kumasi
Laxmi Panthi:	Carbon Footprint and Environmental Documentation of product- A Case Analysis of Road Construction
Rini Farida Rosdiany:	Green procurement practice in the perspective of industrial ecology concept
Heidi Marie Karlsson:	Integration of social responsibility into the Norwegian environmental certification scheme Eco-Lighthouse (Miljøfyrtårn)
Fatima Z. Kiboub:	Oil and gas production waste -Case study, Best Available Technologies and shared lessons
Oddbjørn Dahlstrøm:	Life-Cycle Assessment of a single-family residence built to passive house standard
Jo-Kristian S. Røttereng:	Carbon Capture and Storage in a climate policy perspective: A Norwegian application
Lars Fabricius:	Nanotechnology Human exposure assessment of engineered inorganic nanoparticles in food
Hrefna Rún Vignisdóttir:	Life Cycle Analysis of Scenarios for the Icelandic Vehicle Fleet
Karin Sjöstrand:	The effect of renovation and reconstruction on overall energy consumption and material throughput in the Norwegian residential building stock
Colton Bangs:	Arming the global aluminium cycle for 2050 -Future projections and climate change mitigation
Andrea Dìaz:	Social and Environmental Assessment of Municipal Solid Waste Management Scenarios in Cali: From Landfilling towards Integrated Recycling Schemes
Carine Grossrieder:	Life-Cycle Assessment of Future High-Speed Rail in Norway

Where do former students work?

Research Center for Mining and Metallurgy in Chile Santiago

Umicore, Assitant Manager in Business Development, Hoboken, Belgium

Three previous students work as advisors at MiSA (Miljøsystemanalyse/ Environmental Systems Analysis)

Environmental consultant at Norwegian Armed Forces (Forsvaret)

Environmental ambassador for "Klimaløftet" (Norwegian Ministry of Environment.)

Self-employed consultant

Researcher at the Norwegian Defence Research Establishment

Research assistant at department of Industrial economics and technoligi management, NTNU.

Norwegian Water Resources and Energy Directorate , Renewable energy section

Doctoral study in University of Delaware, US, majoring in Energy and Environmental Policy.

Several students are taking a PhD at NTNU

PhD student. Thesis on transportation and logistics with Edifret (French company), University of Troyes (French university) and NTNU

PhD, Carnegie Mellon

Innherred Trainee Programme w/Norske Skog and Aker Kværner

Trainee in Statkraft

Environmental advisor in Asplan Viak

Scientific employee at the Dutch Competence Centre of Paper and Board (KCPK)

QHSE (Quality, Health, Safety and Environmental) Engineer at Technip Norge in Stavanger

Xynteo

Management consultant i Capgemini Consulting.

Environmental specialist - serving in a German liquid food packaging corporation in the branch office in Shanghai/China.

Assistant Manager of Marketing and Business Development at Umicore in Antwerp, Belgium.

Norwegian Institute of Wood Technology

Statoil

Emisoft

SWECO

Centre for CSR at BI

Norsas (Norsk kompetansesenter for avfall og gjenvinning)

The Business Sector's NOx Fund

Agency for Public Management and eGovernment (Difi)

What do students like about the Industrial Ecology Programme?
(quotes from graduation surveys)

"The people I studied with and the teaching staff."

"Collaborating on research with my advisors, group projects for class work, and social events with Symbiosis."

"I am very impressed by the openness between students and professors, and how many professors are involved in their students."

"Indecol has taught me to think in system view which is very useful to solve problem effectively."

"The multinational, multidisciplinary studying environment. It was very enriching and reviving to meet students from everywhere with different backgrounds, it contributed largely to the success and popularity of the program."

"The researches done and closeness to the newest in the field."

"International, interdisciplinary."

"Multi disciplinary background of the students. Open to choose the subjects that students like."

"The people. The link between problem and solution."

"The fact that I got the chance to work with people from different backgrounds."

"Expertise of teachers specialized in their different topics."

"I liked that you got a feeling of working and studying something that is a fairly new subject, and that by studying this we would become almost an elite within these topics since it is not a course thought many places."

"Possibility to learn an incipient discipline with the most renown experts in the field, which also, are kind, supportive and kind."

"Social environment was very good, thanks to symbiosis. Learning environment was also good."
"Good academic quality. Nice people."

"My classmates--there was a really high density of wonderful, thoughtful people who I learned a lot from."

"How fellow students with different national and educational background shared my interest of environmental issues."

"I really enjoyed the intimate graduate/ post-graduate/professor contact."

"The varied views of different students."

"A good environment with interesting people and research tasks."

"My classmates. I think we were all motivated and helping each other. I also appreciated a lot the practical learning when doing the master thesis and the outstanding advice give, by my advisor, all along the thesis."

Symbiosis - The Association of Industrial Ecology Students at NTNU

Three years since its inception, Symbiosis continues to play an integral role in improving the social and academic experience for Industrial Ecology students studying at NTNU. We have organized many social events and helped ease the transition for newly arriving program students. This year, we've also put more effort into promoting awareness of Industrial Ecology beyond our program by engaging with companies, organizations, and other student groups.

The current board organized it's first social event for the Norwegian Constitution Day on the 17th of May, where we made a traditional Norwegian breakfast for our members and then walked through the national day parade through the city center. The board also organized a formal farewell dinner for the graduating IndEcolers. Throughout the year, Symbiosis continued to plan weekly Wednesday Night Socials, which were a tradition passed down from previous years.

With the incoming batch of 2011 students, the board organized a grand welcome week celebration in the last week of August. The week included great events to break the ice and help students from both years get to know each other. We planned parties, games, hikes and barbecues, ending off with the much awaited cabin trip to Heinfjordstua.

Symbiosis also helped organize many cultural events amongst our students to promote cultural exchange. Events ranged from a workshop on how to cook Chinese dumplings, to Bollywood parties, to eating Får i Kål. To bring in some festive cheer right before the exams, Symbiosis also organized a Christmas Workshop. Symbiosis will soon be going on its annual Åre ski trip, which is one of the most anticipated social events of the year.

In addition to planning social activities, Symbiosis also put great effort into external outreach this year. In late October, we organized the Miljødagen career fair, where we invited environmentally-focused companies to present to students. We also started up the Green Drinks chapter in Trondheim and kicked off our first event right after Miljødagen, which proved to be a great success. Green Drinks events already happen in over 780 cities around the world, and Symbiosis is proud to organize these events to promote networking amongst the environmental community in Trondheim.

To help students find jobs, Symbiosis also held a career planning workshop. We've also tried to increase our online presence this year by creating a new website and being more active on Facebook and LinkedIn. All in all, it's been a great year filled with many memorable moments in Symbiosis.

Contact information:
Symbiosis.boardl@gmail.com

Homepage:
www.ntnusymbiosis.com

Postgraduate School of Industrial Ecology 2011

- written by Thomas Gibon, PhD

For the third time the Postgraduate School of Industrial Ecology offered PhD students the opportunity to get introduced to the latest advances in industrial ecology, and life-cycle assessment in particular. The course was also open to a few master students and young professionals. The course was held from 3rd - 14th of October, and during these two weeks, the participants were invited at NTNU to be presented with core concepts in life-cycle assessment, such as input-output analysis, hybrid assessment and life-cycle impact assessment.

During the first week, Edgar Hertwich gave lectures on the modeling of product systems, as well as methodological issues in life-cycle assessment: allocation, attributional vs. consequential LCA and recycling approaches. All students were first required to prepare a presentation of their own research in order to "break the ice" and foster interaction within the group. Classes then focused on introducing students to the life-cycle approach, through the presentation both of fundamental notions and latest research. After that, students were rapidly introduced to input-output analysis and hybrid life-cycle assessment, via numerous examples. The last day was dedicated to allocation approaches.

In addition to the lecturing by Edgar Hertwich, guest lecturers were invited every day to show the students the current subjects of research at NTNU and how they relate to the course topics. Throughout the week, Thomas Gibon, Anders Arvesen, Guillaume Majeau-Bettez and Francesco Cherubini hence came to lecture on their own research, respectively on energy systems, wind energy, truncation bias in life-cycle assessment and allocation methods.

Mark Huijbregts, from Radboud University Nijmegen in the Netherlands, took over for the second week during which the students were introduced to life-cycle impact assessment and the cause-effect-damage chains of environmental systems. Key methodological aspects that were addressed all along this second week include deriving impact- or damage-oriented characterization factors, uncertainty, use of up-to-date methods (ReCiPe and USETox) and policy relevancy of life-cycle assessment. Passing the course requires attending the lectures and delivering a course paper. Academic students obtain 7,5 credits for passing the course.

The participants to the PSIE 2011 come from a very wide range of universities, research institutes and companies around the world. From agriculture to information technology, from India to Japan, these students have diverse backgrounds, with environmental impact assessment as a common field. Such diversity successfully brings pertinent and vivid questions: in the light of life-cycle assessment, a multidisciplinary environment indeed leads to intense and interesting discussions.

The number of students attending the course was intentionally limited to 30 to facilitate these interactions. Parallel to the course itself, social events were arranged for everyone to enjoy their stay and discover Trondheim and its surroundings. Those included an evening in a traditional "hytte" (cabin), with dinner, games and music; a concert at Studentersamfundet (Trondheim student association's headquarters) held in the context of the biannual UKA student festival, as well as more casual dinners and strolling in the streets of Trondheim. All in all, it is fair to say that all participants' experience in Trondheim was fantastic, both from a professional and personal perspectives, ensuring a solid ground for a perennial concept.

The PSIE group at the student cabin

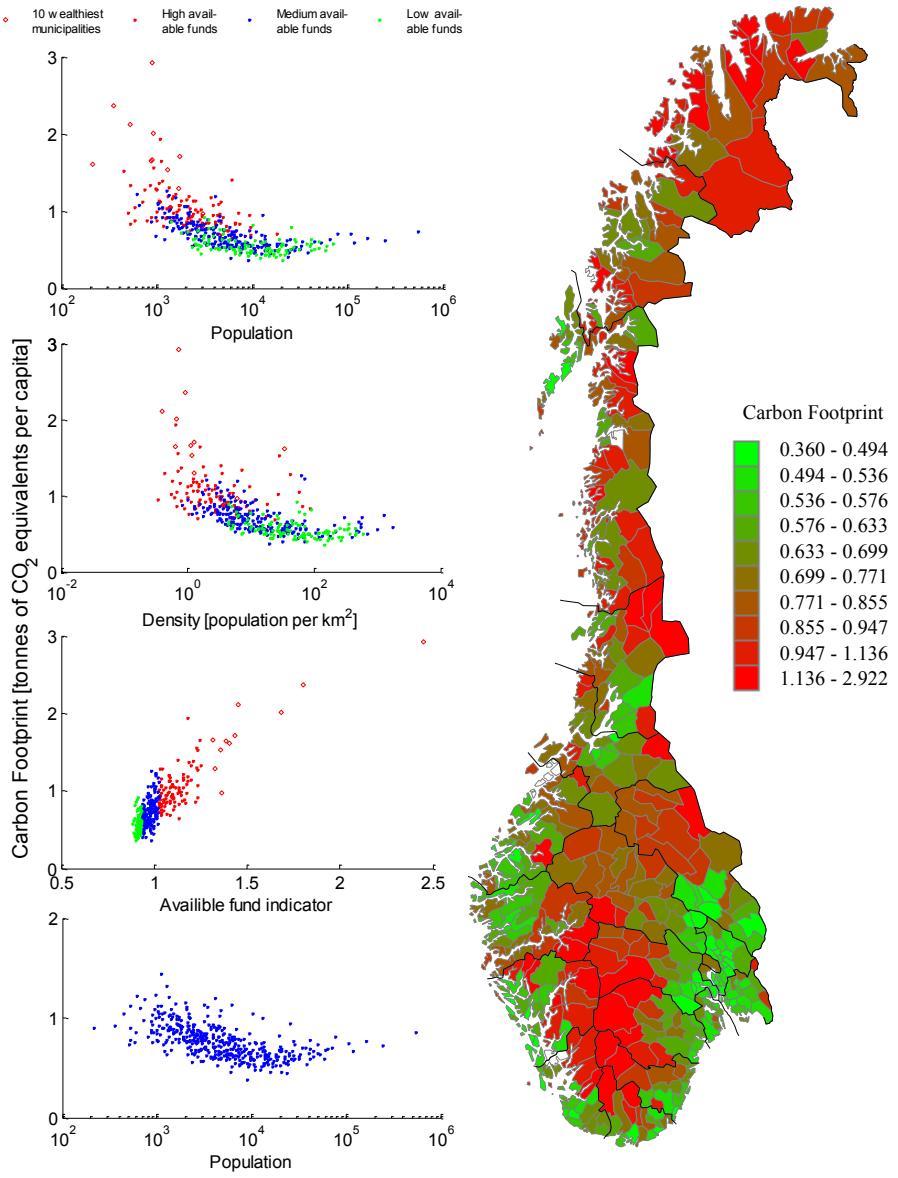
Large differences found in municipal carbon footprints

– by Hogne Nersund Larsen

In my thesis, *Developing consumption-based greenhouse gas accounts -The carbon footprint of local public service provision in Norway*, I investigate the carbon footprint of municipal service provision. Results show surprisingly large differences.

The thesis describes the development and application of a tool to assess and document the life cycle greenhouse gas emissions of municipalities. The model is linked to the financial accounting system of municipalities to calculate the Carbon Footprint (CF) of all purchases/activities made. In particular indirect emissions (Scope 3 according to the greenhouse gas (GHG) protocol) will effectively be accounted for with this system. Consumption-based accounting is often considered to be a superior measure of sustainability, as it includes upstream emissions and, at the same time, excludes emissions from industry activities whose output is consumed elsewhere. This causes a consumption-based inventory to perform well in capturing both outsourcing of municipal responsibilities and handling fluctuations in local industry activities.

When we apply the model to municipalities we find results in the range of 0.36 to 2.9 tonnes of CO2 equivalents per capita. The large differences found were quite surprising. All municipalities have the same set of responsibilities in providing public services to their inhabitants, and differences close to a factor of 10 were not expected. Because of this we wanted to go more into detail on why some municipalities have substantial higher carbon footprint than others. In the figure we provide a color map that gives some indications; large, low density, inland municipalities tend to have quite high carbon footprint. In order to investigate this further we compare the per-capita footprints to a set of municipal characteristics; population, density and wealth.



The results are illustrated in the figure. Two interesting findings are made; first, increased population and density seem to lower the carbon footprint, but only up to a certain size. Once a municipality has reached a size of a Norwegian medium sized city at around 20 000 inhabitants, no clear advantages seem to result from increasing the size further. Second, the degree of wealth seems to heavily influence the carbon footprint, perhaps not very surprising using a consumption-based perspective. However, the bottom-left part of the figure illustrate the results detrended by the wealth factor, and still we find that population is important in determining the per-capita municipal carbon footprint. These findings could play a significant role in the ongoing discussions on the merging of smaller municipalities into larger ones.

Figure:
Municipal Carbon Footprint results for 2007 compared to population, density, available funds and fund adjusted population. Map provided by Statens Kartverk.

Contact person:
Hogne Nersund Larsen
Partner and Senior Advisor
MiSA - Environmental Systems Analysis
hogne@misa.no

Environmental Systems Analysis of Road Transportation Based on Boreal Forest Biofuels – Case Studies and Scenarios for Nordic Europe - by Ryan M. Bright

Road transportation is a sector heavily reliant on liquid petroleum fuels. Demand for road transportation, in particular private vehicle transport, is persistently increasing in Nordic regions. Motivated by concerns over climate change and peak oil, many regions are seeking lower-carbon renewable-based alternatives like biofuels. In Nordic regions, the boreal forest offers a vast resource base from which opportunities to produce a generous supply of biofuels are afforded. However, unlike petroleum based fuels, biofuels and their attributes are not uniform; they can be produced from multiple feedstocks and via a variety of processing methods and technologies – some of which are less environmentally benign than others. There is thus a need to holistically evaluate prospective biofuel production technologies and system designs to ensure that the more sustainable alternatives are embraced.

In the PhD thesis, the main objective was to acquire deeper insight into the climate change impacts and mitigation potentials of forest-based biofuels. Taking a life cycle perspective was fundamental to all analyses in the thesis to ensure holistic evaluation and avoid problem shifting. In other words, climate impacts from all processing and consumption steps of the forest-biofuel supply chain were assessed in the thesis. These climate impacts are essentially attributed to three factors: 1) the amount of fossil fuels consumed and the associated GHGs emitted throughout the life-cycle; 2) the amount of CO2 emitted stemming from biogenic sources, i.e., carbon contained in the forest biomass feedstock or biofuel product which is oxidized during processing or combustion; 3) changes in surface solar reflectance properties (albedo) within the forest when forests are clear-cut harvested to produce biofuels.

In the figure presented below, one may observe the contributions from these three elements for a scenario in which additional forest biomass is extracted from Norwegian forests every year for the production of biodiesel (a volume equivalent to about 1/3rd the current domestic consumption of diesel in road transport) and assuming a 1-to-1 diesel substitution rate. Climate impacts are measured in terms of the time-integrated radiative forcing ("iRF") potential of changes to these three constituents over 100 years relative to a Business-as-Usual ("BAU") scenario whereby fossil diesel consumption levels in road transportation remain constant.

Life-cycle GHG emissions from fossil fuel consumption decrease relative to BAU; however, due to the low efficiency at which energy in forest wood is converted to biodiesel, biogenic CO2 emissions (and thus the corresponding climate forcing) increase relative to a BAU scenario. One may also observe the strong cooling effect from albedo changes in forests, as the mean annual albedo is significantly higher on clear-cut areas relative to forested areas, particularly during the presence of snow in winter. The net total change in climate impact from the forest biofuel scenario relative to the BAU scenario is a slight cooling over 80 years. However, the contribution from albedo cooling is highly region-specific and introduces significant uncertainty into the scenario (yellow).

An invaluable insight gained from the thesis is that assessing the climate performance of biofuels (or any bioenergy product) sourced from boreal forest biomass requires more than a simple summation of GHG emissions over the life-cycle. Forest dynamics must be taken into consideration to quantify land-use related climate impacts, both in terms of atmosphere-biosphere CO2 flux timing and in terms of vegetation change as it affects the albedo time profile. As the analysis presented above implies, robust assessments of the climate consequences of expanded use of biofuels and bioenergy sourced from Nordic forest biomass will require spatially and temporally-explicit modeling considerations.

Contact person:
Ryan M. Bright
Post-Doc
Industrial Ecology, NTNU
ryan.m.bright@ntnu.no

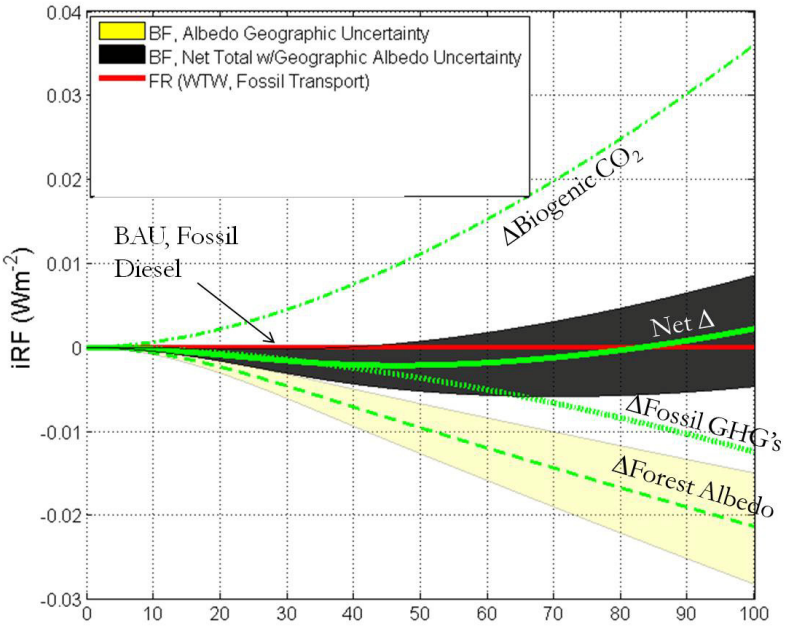


Figure: Time-integrated radiative forcing (iRF) impacts associated with replacing ~38 PJ/yr. of fossil diesel with wood-based diesel in Norwegian road transport.

Agent-Based Modelling and Simulation of Clean Heating System Adoption in Norway - by Bertha Maya Sopha

Introduction: Space heating is the single most energy consuming process in Norwegian households and consequently have an important role when environmental impacts from energy production and consumption is to be reduced. The convergence toward a sustainability path therefore depends, to a great extent, on the diffusion of environmentally friendly heating technologies. In Norway, supply security of electricity has become an issue and is likely to be sustained in the future. The Norwegian government has thus attempted to reduce oil-based heating system and electricity consumption by supporting more sustainable heating technologies. Subsidising of air-to-air heat pumps kick-started the diffusion of these and this is continued even after the subsidy was stopped. However, similar subsidises did not lead to a significant diffusion of wood-pellet heating. This research aims at gaining a better understanding of consumers' decision-making on heating systems and to assess the potential application of Agent-Based Modelling (ABM) in exploring mechanism underlying adoption in which heating system adoption by Norwegian households is taken up as a case study. The research contributes particularly to the understanding of households' decision-making on a heating system, which factors; technical, economic-demographical, social, and psychological, are crucial in heating system decision-making, and which potential interventions leading to higher adoption of clean heating system.

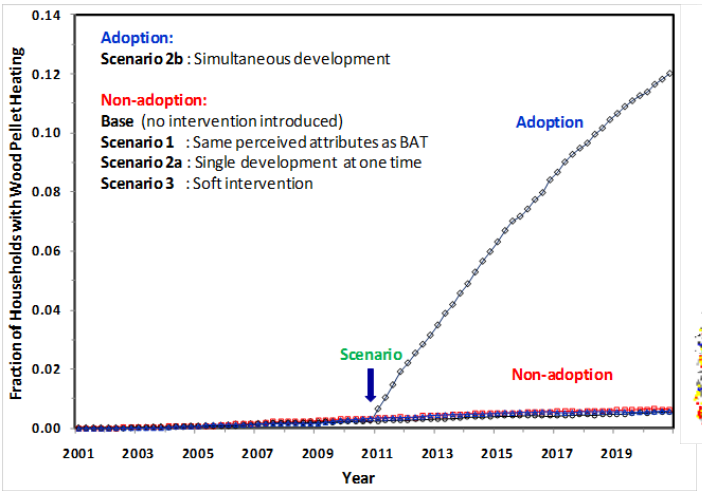
Methodological approach: An interdisciplinary approach, applying established theories from various disciplines, i.e. technology management, psychology, and complex system, to provide a more comprehensive conceptual model of Norwegian households' decision-making of a heating system. The conceptual model, which was built based on theoretical consideration and empirical findings from both the literatures and this research, was implemented in Agent-Based Modelling (ABM). Empirical ABM, parameterized by an empirical survey, simulates diffusion resulted from decentralized heterogeneous households' decision-making and social interaction.

Data: Data used for the research was based on a mail survey, carried out in autumn 2008 and specifically designed to acquire empirical facts of households' decision-making and to validate simulation model. Survey sample consisted of 1500 Norwegian households drawn from population register and 1500 wood pellet users in Norway. The response rates were 19.4% and 44.6% for population sample and wood-pellet sample respectively.

Major findings: The research conveys findings from both empirical analysis and simulation study. Major findings from the empirical analysis show that, in addition to socio-demographic factor, both information and functional reliability are important features in decision-making of a heating system. Moreover, using an integrated psychological model, this research provides evidence that adoption decision of wood-pellet heating is a deliberative decision. Simulation results demonstrate that the generated data from simulation is reasonably able to generate independent historical data at both macro- and micro-levels. A set of scenarios have been selected and suggested that the potential interventions toward higher adoption of wood-pellet heating includes relative advantages of wood-pellet heating and simultaneous development of wood-pellet heating (supporting Diffusion of Innovation theory and hypothesis from wood-pellet heating literatures respectively), whereas focusing norms/values is not a promising intervention (in line with the finding from the empirical analysis).

Interdisciplinary aspect within industrial ecology: This research has integrated various competences at Industrial Ecology Programme such as psychology and technology management, to allow multiple perspectives and richer insights of various aspects; technical, economical, psychological, and social factors, in examining a problem. Agent-Based Modelling (ABM), one of modelling tools in Industrial Ecology, is coupled with empirical research and demonstrates a resounding success of its application, hence deserving to be exercised in a different domain. In turn, one of the findings indicates that Norwegian households have different perception of which environmental friendly heating system highlights the necessity of a study on environmental performance of various heating system options in Norway using LCA (Life Cycle Assessment) which has been one of core competences at Industrial Ecology Programme. Although challenging, interdisciplinary study is essential because sustainability issue to which Industrial Ecology refers IS a complex system.

Contact person:
Bertha Maya Sopha
bertha.sopha@ntnu.no



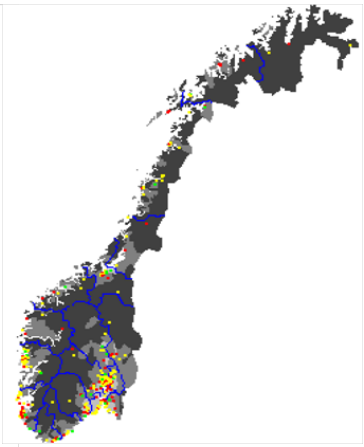


Figure:
Left: Scenario results for wood-pellet heating adoption in Norway (2001–2020).
Right: Spatial result for scenario of simultaneous development (red: electric heating, yellow: heat pump, green: wood-pellet heating)

Environmental evaluation of carbon capture and storage technology and large scale deployment scenarios - by Bhawna Singh

Carbon Capture and Storage (CCS) is a technology to capture CO2 from flue gas or CO2 rich stream and sequester it away from atmosphere. When used in power plants, it reduces CO2 emissions from electricity generation while continuing the use of fossil fuels required to satisfy the increasing energy demand. However, CCS is an energy intensive process, and demands additional energy, chemicals and infrastructure. The capture processes may also have certain direct emissions to air (NH3, aldehydes, solvent vapor etc.) and generate solid wastes from degradation byproducts. A trade-off in environmental impacts is expected, and with the large-scale application of CCS needed to make any significant reduction in CO2 emissions, these potential trade-offs can become enormous in magnitude. Therefore a systematic process of evaluation of complete life cycle for all available CCS options and large-scale CCS deployment scenarios is needed. Life Cycle Assessment (LCA) methodology is well-established and best suited for such analysis.

The results of the study reveal that the CCS systems achieve a significant reduction of greenhouse gas emissions but have multiple environmental trade-offs depending on the technology. The implementation of CCS reduces the greenhouse gas emissions by 74%, 78%, and 76% from coal systems with post-combustion, pre-combustion, and oxyfuel capture, respectively. For natural gas CCS systems, the reduction in GHGs is 68%, 64%, and 73% for post-combustion, pre-combustion, and oxyfuel capture, respectively. For cases with CCS, a major portion of GWP (52-73%) for natural gas emanates from the fuel production chain, and 17-42% from the power plant. For coal CCS systems, fuel combustion is still the major source of GWP (52-56%). There is a net increase in all other environmental impact categories except some reduction (7-15%) in acidification (TAP) and particulate formation (PMFP) for post-combustion coal CCS system due to co-capture of SO2 and particulates from the flue gas. Human toxicity impact increases by 40-75%, terrestrial ecotoxicity by 60-120%, and freshwater eutrophication by 60-200% for the different technologies.
However, since climate change due to global warming is attributed as the maximum damage causing impact, the end-point damage assessment confirms that CCS systems greatly reduce human health damage and ecosystem damage.

The results for environmental evolution of CCS systems show that the future techno-economic developments will enable a significant reduction of about 30% for coal and 20% for natural gas fuel by 2050 across all impact categories. The information so obtained, coupled with the electricity scenarios brings an understanding of the environmental implications of large scale deployment of carbon capture and storage technology and show the clear advantage of ACTmap and BLUEmap scenarios (mitigation scenarios with global CCS integration) over the Baseline scenario having significantly lower impact potential scores for all impact and damage categories from coal and natural gas based electricity generation.

This research work evaluates and compares different CCS options for coal and natural gas, discussing various trade-offs and net-benefits. This information brings a holistic environmental understanding of CCS as necessary to avoid any problem shifting (as with bio-fuels shifting problem to food-crop land-use). The study also discusses the environmental relevance of CCS in more understandable terms of damages to human health, ecosystem and resource depletion, thus facilitating the decision makers to derive policies for sustainable development. The study represents an early application of end-point indicators from the ReCiPe method, giving simple and comprehensible results, and justifies a dual-approach for environmental assessments, presenting mid-point results to understand environmental potentials and identification of key areas to reduce the adverse impacts and end-point results to present comprehensible information to decision makers. This study also presents a methodological framework for futuristic assessment and scenario assessments incorporating the learning in processes, influence on background processes, variable demand etc.

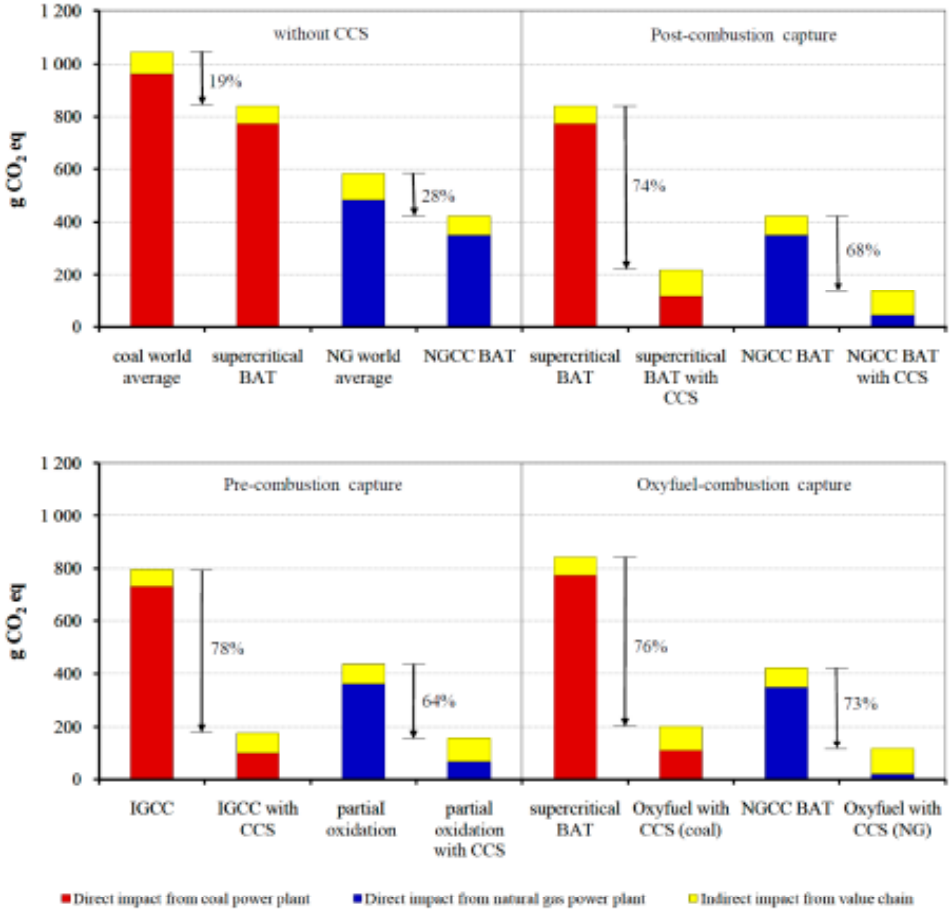


Figure:
Global Warming Potential (GWP) for 1 kWh electricity generation

Research activities related to the built environment

One of the applied areas of industrial ecology research at NTNU is built environment, with a variety of research projects examining sustainability issues of buildings and infrastructure, i.e. various subsystems of the construction sector. Below are given key information about some of the research activities in two of the groups active in this area.

The Building and Material Technology research group

Contact person: Associate Professor Rolf André Bohne, Dept. of Civil and Transport Engineering - rolf.bohne@ntnu.no

The Building and Material Technology research group had a busy year during 2011. Not only were the research and teaching activities growing, we also join forces with another research group, the "Project management and construction engineering", to form a new research group called "Building and Construction Engineering".

Viable construction is the main theme for the new research group. The requirement of sustainability has implications on the choice of measures, in order for the investments the project represents, to secure the overall largest possible net benefits. Focus should therefore be economic, social and environmental benefits.

The research group develop systems, policies, methods, tools and techniques that are used by Norwegian and international industrial project owners, consultants, contractors and property managers. One example of this is the Concept project where research has influenced government projects in Canada, China, Germany and Denmark in their implementation of a quality assurance system.

2011 was a busy year for the research group, as demand for our expertise in building and construction engineering is increasing as the society realizes that civil engineering is of utmost importance and play a key role in creating a sustainable future. Tunnels - especially for Hi-speed railways, zero-emission buildings, as well as renovation and retrofitting of existing buildings are all activities we are involved with at the moment. The combination of building and construction engineering with new digital tools and methods will make powerful tools in creating more viable solutions for the future. It is not only a matter of choosing the right projects, but also of doing them right.

We also find ourselves in a shift from designing zero and plus houses, towards working on sustainable neighborhoods and cities. Getting people to cluster together is necessary in order to reach sustainable societies in the future. But can also be highly unsustainable when implemented wrong. To understand the dynamics and thresholds of neighborhoods and cities is thus of high importance for a viable and sustainable future.

The Industrial ecology in environmental engineering research group

Contact person: Professor Helge Brattebø, Dept. of Hydraulic and Environmental Engineering - helge.brattebo@ntnu.no

The group has strengthened its built environment research focus during 2011. The research aims to understand medium and long term strategies for transition to more sustainable solutions for building stock and infrastructure systems, using methods from the field of industrial ecology, such as MFA, LCA and LCC, in combination with dynamic analysis and scenario modeling. Much of the research is addressing urban systems and solutions.

One example is our participation in the EU7FP TRUST project (TRansitions to the Urban water Services of Tomorrow), launched in May 2011, where NTNU has the main role in developing a Metabolism Model concept for the urban water cycle systems, so that future strategies and solutions for infrastructure and governance intervention options within the water and wastewater sector can be quantitatively analysed with respect to all resource inflows (energy, materials, chemicals), wastes and emissions, and resource recovery, including their economic, environmental and social impacts. The work builds upon previous studies of the city of Oslo, and the doctoral thesis of G. Venkatesh, who is now a post-doc in the TRUST project.

Another example is research for the road authorities. In the ETSI project we have developed an LCA-model for a detailed analysis of road bridge designs, for the national road authorities in Finland, Sweden, Denmark and Norway. This tool is now to be implemented in practice, in order to help bridge designers improve the life cycle solutions and environmental qualities of bridges. We also developed a module for analysis of life cycle carbon emissions of road systems, as part of the EFFEKT software that is used for cost-benefit assessment in early-stage planning of roads in Norway. On this background we were selected as partner with KTH Stockholm, for development of a similar tool, in the LICCER project funded by the roadERAnet programme (Energy - Sustainability and Energy Efficient Management of Roads) funded by Germany, Denmark, Ireland, Netherlands, Norway, Sweden and United Kingdom. This work builds upon research by PhD-student Johanne Hammervold.

A third example is research on energy flows and GHG emissions from the national Norwegian stock of residential buildings. Our research portfolio in this area includes work by several PhD and MSc students, over the last years, and has benefitted from the use of dynamic MFA models in combination with the use of type-age matrix housing typologies. Our current research strategy is to study more in-depth the characteristics and dynamics of segments of the building stock, linking this to renovation strategies, and advancing our modeling methods by developing more precise typologies for the Norwegian housing stock, in collaboration with research partners in the EU7FP TABULA project who have been developing such typologies for other European countries. This work builds upon previous research by PhD-students Håvard Bergsdal, Igor Sartori, Stefan Pauliuk and Nina Sandberg.

The final example is research on Sustainable Neighborhoods, where our group is partner in an interdisciplinary project for the assessment of how to develop a greenfield urban local area, Brøset, in Trondheim. Our role is to examine how strategies for urban infrastructure solutions should be chosen, under the premises of low-carbon emission targets. This work builds upon research by PhD-student Helene Slagstad.

Different ongoing projects on Environment, CSR and Sustainable Development at IØT-NTNU

Innovation in Global Maritime Production - 2020 (IGLO-MP2020)
(website: www.iglo-mp2020.no)
Project period: 2008-2012

IGLO-MP 2020 is a knowledge-building project with user involvement (KMB) with collaboration between the Norwegian University of Science and Technology (NTNU), Marintek and the industrial partners Ulstein International AS, Pon Power AS, Siemens AS and Fiskerstrand Verft AS. The project draws on the expertise in international institutions, on Roll Royce Maritime and the Norwegian Center of Expertise Maritime in Ålesund (NCE Maritime). The overall focus of this KMB is to strengthen the competitive capabilities of the Norwegian maritime industry in order to improve competitiveness. IGLO-MP 2020 has identified a few key areas and themes, which the consortium members perceive as critical for future development and sustainability of the maritime industry in Norway. These are elements which are believed to provide Norwegian ship owners, ship designers, ship consultants and maritime equipment suppliers with competitive advantages in years to come.

Sustainable Development, Production and Communication in Hungary.
Project period: 2008-2011

This is a project financed by the Norway Grant mechanisms to Hungary. The Norwegian contributions are on the topics "From Environmental Product Declarations to Product Development in SMEs", and "Environmental Management in Global Value Chains". The project activities have focused on training session for industrial participants from SMEs on how to develop Product Category Rules (PCR) and Environmental Product Declarations (EPD) and transfer of experience between Norwegian and Hungarian practitioners EPD, their use in marketing and in product development. Through workshops case-examples from Norwegian and Hungarian industries are debated. Results are presented in seminar and in papers for scientific Journals.

CSR as a Strategic Tool for Sustainability Focused Innovation in Small and Medium Sized Enterprises
Project period: 2010-2012

This project is a collaboration between the Norwegian School of business (BI), University of Stavanger and NTNU. The project is headed by BI. The primary objective of the project is to strengthen the insight into how CSR contributes to sustainable innovation in small and medium sized enterprises and to contribute to building a Norwegian competency cluster capable of advising industry and policy-makers in this field. The secondary objective include the following: 1)To push the research frontier in the field and contribute to the international literature; 2) At the level of business, to contribute to useful practical insight into management tools, technology development approaches and innovation oriented business models for SMEs; 3) At the level of policy: to suggest additional policy tools and approaches to further innovation, sustainability and economic growth. The project is financed by Norges Forskningsråd.

Harmonization of PCR and EPD, organized through EPD-Norge
Project period: 2011

This project is a collaboration between NTNU, Sintef Byggforsk and Østfoldforskning. The aim of the project is to develop guidelines for development of product category rules (PCR) and environmental product declarations (EPDs) with the goal to make EPDs comparable for products with similar functional unit. The project is financed through EPD Norge.

Cleaner Technology and Environmental Management (CTEM), Environment Urban Sector Program Support, Ministry of Economic Affairs; Bhutan.
Project period: 2009 – 2010.

This project in Bhutan is sponsored by Danida to introduce concepts of cleaner technology and environmental management (CTEM). The industry sectors include wood, food, cement, mining, steel and ferrous alloys. Over twenty companies have participated. A generic guideline has been created, based on similar projects in Norway, to assist these companies as they conduct their first cleaner production assessments. The project has involved researchers from NTNU, from Denmark and France.

Biochar on acidic agricultural lands in South-East Asia: Sequestering carbon and improving crop yield
Project period: 2010 - 2013

NTNU will in particular contribute to Work Package 6 with our expertise and experiences on LCA and its application on social aspects as well as the traditional environmental LCA. A special focus will be on the development of environmental and social life cycle assessment for application on biochar, especially its contribution to the development of impact assessment and weight models for land use areas. NTNU will further contribute to the use of life cycle management and systems engineering in new project areas.

ShipSoft
Project ShipSoft is a preliminary project where the opportunities for integrating system analyses in marine systems design is explored. By investigating the informational, computational and analytical requirements for assessing marine design, opportunities and barriers for adopting such methods in the industry is identified. The project is connected to IGLO-MP 2020 with partners from Ulstein Design and Solutions, Pon Power, Fiskerstrand Shipyard and Fjord1. The project period spans from 2011-2012.

CSR Competence Network
CSR Competence network aims to increase the CSR-competence in the intersection between education, research and the industry. The network is a collaboration-project between companies and knowledge partners from the region, where seminars, lectures and workshops are used to share and create new knowledge within the field. The network was established in 2011 and will last until 2012. (website: www.csr-norway.no)

Contact person:
Professor Annik Magerholm Fet
Annik.Fet@iot.ntnu.no

Dina Margrethe Aspen

Dina graduated from the MSc - programme in 2011 and is currently working as a **PhD student** at the IØT-department,NTNU.

Asked of why she wanted to do a career at NTNU Dina says; *"My initial plan was to get some work experience and perspectives before I came back to do a PhD. However, the combination of a very motivating supervisor and an interesting research project made me pursue this track immediately after my master. I find it quite surrealistic that as a PhD you are allowed to spend 3-4 years diving into a project of our own interest where the ultimate goal is to develop new knowledge - and get paid for it!"*

Dinas main focus in her PhD thesis is to look into how one can integrate the perspectives, methods and models from Industrial Ecology in a marine design context; *"The maritime industry has a great potential at using life cycle management approaches in early decision-making processes. However since marine systems are large and complex, operate in the interface between air and water and have long service lives, there are many challenges at managing their sustainability performances. Luckily, I'm working with highly motivated and innovative companies. After my thesis, I am eager to get some practical work experience but wish to maintain my affiliation with academia."*

Laxmi Panthi

Laxmi also graduated from the MSC - programme in 2011, and is currently working as a **research assistant** at the IØT-department, NTNU.

"The MSc programme at NTNU gave me an opportunity to further specialize in the environmental politics and management. Having gained knowledge on both environmental analysis and environmental policy & management, I can now contribute significantly in making environmental strategy planning ranging from organizational level to the national level."

Asked of what she has learned in the MSc programme that makes her attractive on the job market, and in reaserach, she says: *The holistic approach of industrial ecology helps to understand environmental cause effect relations with clear view on how to minimize environmental problems. My prior knowledge on natural resource management and social anthropology are also helping me to better understand the theme of Industrial Ecology discipline, meaning Industrial system should mimic the balance system of natural ecosystem to continue the world on sustainable basis and it is the social responsibility of economic actors on society to take care of the earth for its sustainability. Therefore, I have belief and confident that my knowledge of industrial ecology can contribute in environmental research activities. Thus, I accepted happily to work as a Research assistant at NTNU.*

Marina Magerøy

Marina also graduated from the MSc-programme in 2011, and is currently working as a **Higher Executive Officer** at the Health Environment and Safety Division at NTNU .

Asked of what she has learned from the MSc programme in Industrial Ecology,she says: *"The Industrial Ecology programme has given me a holistic and interdisciplinary view on sustainability. Even though I have specialized in environmental management I have the knowledge and understanding of the analytical methods and tools which I feel gives me a professional advantage within the sustainability field."*

Asked of why she ended up at NTNU after she graduated she says:*"It was incidental that I ended up with NTNU as an employer, but working for such a big and diverse organization has been very interesting and instructive. My job at NTNU has given me the opportunity to put knowledge learned through the Industrial Ecology masters and the environmental management courses into practice. I am currently assisting NTNU in developing an environmental policy. Among my tasks have been to map the current environmental efforts of the university, look at how other universities are organizing their environmental work and to provide a presentation of various choices of ambition levels for environmental goals and the consequences of each choice."*

Professor Annik Magerholm Fet manages the research group within environmental management and corporate social responsibility (EMCSR) at the department of industrial economics and technology management, IØT, at NTNU. The group works to improve decision-making in industries by integrating the tools and methods from IE.

Our role relative to industrial ecology is to operationalize the principles and practices from this discipline in order to enable industries to implement them. Our recent research projects involve companies from the maritime sector, the sector for production of common goods like the furniture sector and suppliers to the built environment, and the food sector where we currently work on a carbon footprint standard for the fishery sector.

Her experience from managing industrial sustainability projects is that IE skills and knowledge are highly requested by industry. *"The students from the Industrial ecology program have the skills that we need in the research projects. It is quite important to recruit IE students to these projects as they have the skills and knowledge that is quite requested by industry both in their daily work as well as in more proactive project activities that help the company to move forward. The students are also excellent candidates for relevant multidisciplinary PhD-programs due to their ability to understand systems behaviour, system interactions and their impacts."*

Fet tries to include students from the IE program into her research projects from the very beginning. "I try to involve the students in these projects as early as possible. In the course TIØ 4195; Environmental management and corporate governance, the students get the chance to collaborate in groups with a real case study. We also connect students to case companies when working on their project and master theses. In addition, the apprentice program has been quite successful for the students that apply for project within this field - they all become active in ongoing research projects through this program."

Design for Sustainable Behaviour

At the Department of Product Design (IPD), one of the main research themes related to industrial ecology is design for sustainable behaviour; a theme that is gaining research interest fast. Design researchers increasingly acknowledge the importance of their potential role; through design they can have a profound influence in altering users' behaviour into more sustainable behaviour and consumption patterns. As a result, fuelled by dedicated conference sessions, international workshops and a number of pioneering journal articles, all of which IPD has been visibly involved in, in recent years a 'design for sustainable behaviour' research community has developed. In earlier years of ecodesign research, attention for the use phase has mainly focused on using technology to achieve increased resource use efficiency. Now it is understood that by understanding user behaviour, and using that in design solutions including shapes, colours, affordances, 'nudges' and so on, up to 30% 'additional' savings in for example energy or water consumption may be achieved. Research into Design for sustainable behaviour strategies aims at exploring design strategies for reducing behaviour-related environmental impacts of product and systems, although they have also been proposed for more general applications to persuade users into more socially desirable behavioural patterns. This 'design for sustainable behaviour' community embraces insights from a various relevant scientific fields, such as social psychology, persuasive technology, sustainable consumption, industrial ecology, stakeholder analysis and interaction design. Also within these fields, interest in looking at design as a possible source for solutions is growing, creating a mutual cross-fertilisation of ideas and concepts.

On-going research focuses on exploring relevant concepts and disciplines to provide an understanding of relevant user, product and system aspects that need to be studied and incorporated into design strategies for sustainable behaviour – ultimately to facilitate the successful application thereof. Attempts to conceptualize, frame and structure research constructs, influencing factors, and strategies are abundant, but results thereof are not established yet as a common language that facilitates research progress. In recent years also several case studies have been published focusing on the collection of relevant data for designing solutions that inform, persuade or force sustainable behaviour. This process of selecting, generating and exchanging case study data is still rather unorganized and ad-hoc, but this is largely an unavoidable consequence of an immature research area trying to mature.

IPD aims to build up a leading position in this emerging research field, and we are well on the way. Three PhD projects are strongly related to this theme. Ida Nilstad Pettersen has done extensive case studies related to dishwashing, entertainment and heat regulation products, in an effort to better understand and describe the social practices related to them and the industry's ability and willingness to invest in doing so. Funded by a NFR project, Kirsi Laitala, employed by SIFO, addresses a range of practices relevant for clothing design including how and why people buy, wash, dry, keep, repair and throw away clothes. One of the aims of the research of Johannes Zachrisson is to develop a guide to help designers in selecting appropriate design strategies for influencing user behaviour. His research is partly inspired by the work of IndEcol colleague Christian Klöckner and his colleagues, and recently he has started a project with CenBio and Jøtul to identify opportunities for designing wood stoves that facilitate appropriate firing behaviour. This is a relevant project, because research shows that many Norwegians are either too ignorant or too lazy to fire wood in an environmentally responsible way – or it is just too difficult for them.

The research group at IPD is making an effort to disseminate this new perspective in sustainable product design; for example through a Technoport Talk presentation in May, which can be seen on YouTube (just google 'Casper Boks' and 'Design for Sustainable Behaviour'), and Johannes Zachrisson's participation in the Norwegian 'Forsker Grand Prix' competition, where PhD students pitch their research in front of a general audience. The group is supervised by Professor Casper Boks, who, just before the end of the year, managed to grab a Best Paper Award at the biannual EcoDesign2011 conference in Japan for his paper titled "Design for Sustainable Behaviour Research Challenges".

More importantly, in September 2011, Dr. Martina Keitsch, a former IndEcol postdoc, joined IPD as an associate professor, and her experience with the interface between industrial ecology, sustainable design and social sciences is a welcome contribution towards building up and extending our research activities.

Contact Person:
Professor Casper Boks
Casper.Boks@ntnu.no

Lifecycle assessment of batteries for electric vehicles

The world seems posed for another boom in passenger car and light-duty vehicle ownership. Simultaneously, the greenhouse gas emissions and local air pollution caused by these vehicles has already reached unsustainable levels. In this context, electric vehicles (EV) have recently stirred much public, political and scientific interest. All hope in the deus ex machina of a technological breakthrough.

With no direct emissions and motors that are not plagued by thermodynamic limitations, EVs are indeed environmentally interesting, depending on the manner in which the electricity is produced. However, the Achilles' heel of EVs has long been the storage of this electricity aboard the vehicle. Surprisingly, relatively few life cycle assessments (LCA) have focussed on the environmental impacts of traction batteries.

At the Industrial Ecology Programme, as part of the ECAR project, we set out in 2009 to produce a public inventory and a transparent LCA of traction batteries for plug-in hybrid and purely electric vehicles. The primary goal was to assess the influence of these new technologies on a range of environmental impacts, not only climate change. Furthermore, we also aimed to identify the most environmentally intensive production chains, so as to guide further development of traction battery industry.

We assessed a nickel metal hydride (NiMH) battery and two different types of lithium-ion batteries, respectively based on nickel-cobalt-manganese oxide (Li-NCM) and iron phosphate (Li-FP) electrodes. Our study covers the whole production chain and the use of the batteries. Even though no emissions occur during the use-phase, the batteries waste different amounts of electricity depending on their efficiency levels.

Overall, we found higher global warming impacts than had been previously reported. This is mostly due to differences in energy estimates for material processing and battery manufacturing. The environmental profile of NiMH is mainly determined by its important nickel requirements. Fo Li-ion batteries, the mining activities required for the production of copper account for 30-50% of the lifecycle toxicity and ecotoxicity impacts. The inclusion of fluorinated compounds in the Li-ion electrode paste and electrolyte may also have significant impacts on the conservation of the ozone layer.

Because of their lower energy capacity and efficiency, NiMH batteries were found to cause significantly more environmental damage than Li-ion batteries for the same amount of stored energy. Amongst Li-ion batteries, Li-FP batteries require materials with lower toxicity footprints and are predicted to have longer life expectancies and stabilities, giving them a slight edge on Li-NCM batteries.

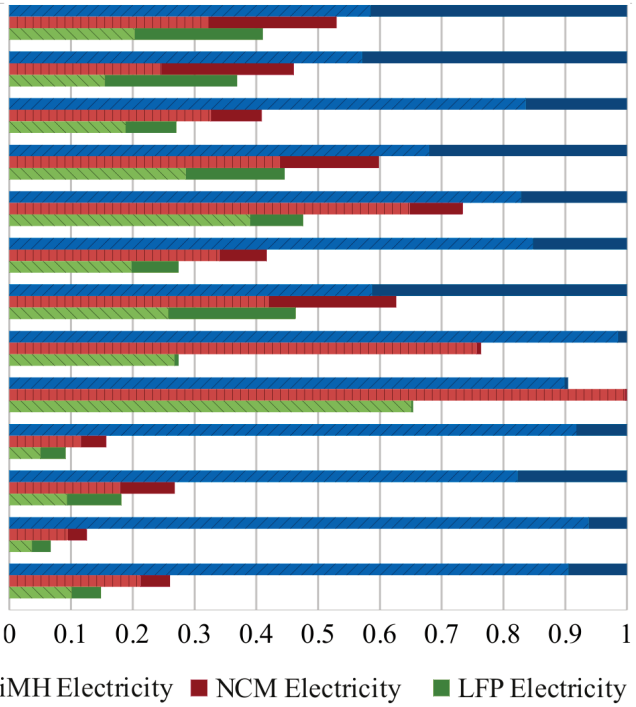
Our work culminated this year in the publication of an article in Environmental Science and Technology and in the inclusion of our results in the inventory of a complete electric vehicle, which is currently undergoing peer-review with the Journal of Industrial Ecology. We are currently taking the first steps towards a closer partnership with battery industry experts in the hope of reducing the uncertainty associated with our inventories.

Reference:
Majeau-Bettez, G. ; Hawkins, T. R. ; Strømman, A. H. Life Cycle Environmental Assessment of Lithium-Ion and Nickel Metal Hydride Batteries for Plug-In Hybrid and Battery Electric Vehicles. Environ. Sci. Technol. 2011, 45 (10), 4548-4554

Contact persons:
Guillaume Majeau-Bettez
guillaume.majeau-bettez@ntnu.no

Professor Anders H. Strømman
anders.hammer.stromman@ntnu.no

FU: charge-discharge 50 MJ		NiMH	NCM	LFP
GWP_{100}	*kg CO_2-eq*	3.6	1.9	1.5
FDP	*kg oil-eq*	1.0	0.46	0.37
$FETP_{inf}$	*kg 1,4-DCB-eq*	0.13	5.1×10^{-2}	3.4×10^{-2}
FEP	*kg P-eq*	4.6×10^{-3}	2.7×10^{-3}	2.0×10^{-3}
HTP_{inf}	*kg 1,4-DCB-eq*	5.6	4.1	2.7
$METP_{inf}$	*kg 1,4-DCB-eq*	0.13	5.6×10^{-2}	3.7×10^{-2}
MEP	*kg N-eq*	4.1×10^{-3}	2.5×10^{-3}	1.9×10^{-3}
MDP	*kg Fe-eq*	1.1	0.85	0.30
ODP_{inf}	*kg CFC-11-eq*	1.0×10^{-5}	1.1×10^{-5}	7.5×10^{-6}
PMFP	*kg PM10-eq*	2.4×10^{-2}	3.7×10^{-3}	2.2×10^{-3}
POFP	*kg NMVOC*	1.7×10^{-2}	4.7×10^{-3}	3.2×10^{-3}
TAP_{100}	*kg SO_2-eq*	9.9×10^{-2}	1.2×10^{-2}	6.6×10^{-3}
$TETP_{inf}$	*kg 1,4-DCB-eq*	1.2×10^{-3}	3.1×10^{-4}	1.8×10^{-4}



Tailoring Intervention Instruments and Policy to Promote Emission Reduction in Norway: Applying the Self-Regulation Model of Behavioural Change

For the development of a policy strategy that aims at a relevant reduction of CO2-emissions in Norway it is crucial to identify and understand the most relevant behaviours and identify starting points for effective intervention strategies. Within these behavioural domains that are characterized by a rather high degree of habitualization, conventional intervention techniques have proven to have a limited plasticity, realizing only a fraction of the reduction potential.

This project takes a new perspective on this issue by a three step multidisciplinary research approach. First the impact of a variety of possible relevant behaviours is identified in a collaborative effort of psychology and environmental science based on life-cycle assessment and input-output analyses. Second selected behaviours are analysed empirically on the basis of an appropriate psychological model of behaviour change. As the behaviours we will focus on can be assumed to be daily routine behaviours (e.g. daily meat consumption) we will mainly apply the Self-Regulation-Model of behaviour change, which is a stage model that stems from the domain of health related behaviour and has recently been successfully transferred to explain change processes in environmentally significant everyday behaviours. Third we will develop suggestions for a national social marketing campaign that is tailored to the specific needs of the Norwegian population. The marketing campaign will be empirically tested on a representative sample of Norwegian households and recommendations for up scaling it will be given. At the moment there are very little government interventions or programs targeting households (consumption) in Norway.The purpose of this project is to produce new knowledge about effective climate policy instruments. Its aim is to provide a better knowledge basis for decision-making in connection with efforts to reduce greenhouse gas emissions. Dissemination of findings to stakeholders is therefore given particular attention. By applying a psychological model to identify sub-groups in the population with respect to their readiness to change, a tailored marketing and intervention strategy is developed and tested that is potentially more effective than addressing the population with a non-specific strategy.

Background and status of knowledge

According to recent studies, the level of change individuals are willing and able to implement into their everyday lives differs, and changing lifestyle components is a multi-stage process which needs to be understood from a psychological perspective. An everyone-gets-the-same-treatment approach seems to be both cost-inefficient and potentially counterproductive as non-adaptive intervention strategies might cause resistance or reactance.

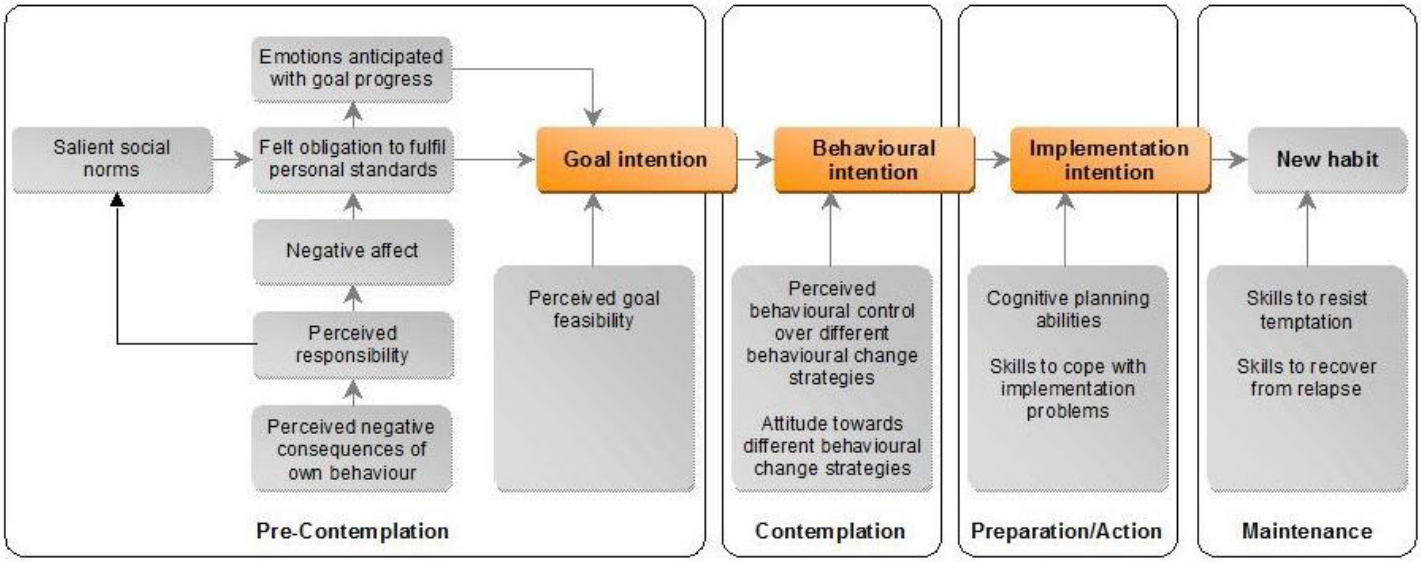
The figure displays the model which will be used as a basis for the proposed study. The central assumption of the model is that people are under certain conditions willing and able to change their behaviour even if the behaviour is deeply anchored in everyday routines. Usually, such behaviour would be considered habitual and difficult to change. The model assumes that this process of intended behavioural change occurs in a series of distinct stages which are linked by critical transition points that mark the transition from one stage into the next.

Stage specific intervention techniques

Using the described model as a theoretical basis for designing intervention campaigns is promising because it identifies stage specific levers to help people reach the next stage in changing behaviour. It has been demonstrated before in health psychology that specifically tailored interventions to the stage of change people are in increase the success rate of the intervention programme. The model is helpful in designing intervention campaigns in two ways: First, it defines distinct transition points that can allocate people in one of the stages of change and thus be used as a tool to identify the sub-groups. Second, it provides theoretical insight into the processes within each stage and thus identifies possible leverage points to intervene.

Identifying relevant behaviours

The variety of individual behaviours that directly or indirectly contribute to emission of greenhouse gases is so long that it is necessary to narrow down the focus of this project to a selection of target behaviours. Based on the feasibility of psychological change of the targeted behaviour; the importance of potential domains in Norway, the plasticity of both behaviours, their impact on the environment and the frequency of the behaviour in everyday lives, it is here decided to focus on meat consumption and purchase of new cars.



Research design
This longitudinal study will be divided into two main studies: the meat consumption study which will be launched first in 2012 and then followed by the new car purchase study in 2013. The data collection will be based on an online intervention platform with included questionnaire studies. A representative stratified random sample of approximately 15 000 Norwegians will be drawn and invited to participate. Participants will be recruited via ordinary mail to reduce self-selection effects that influence online surveys. A reminder letter will be sent and a lottery will be introduced to increase participation. Three waves of measurement will be conducted in a longitudinal control group design to identify the short and medium term intervention effects. One fourth of the sample will be randomly assigned to the control condition, one fourth to a tailored intervention condition, one fourth to a random intervention condition and one fourth to a total group that will receive all interventions. The control condition will not receive interventions but only go through three waves of measurement. The tailored intervention condition will (after each individual is grouped into a specific stage of change) receive an intervention package tailored to the specific stage and the random intervention group will receive a randomly selected intervention package.

Initial findings on meat consumption
Attempts to quantify the CO2 emissions in Norway arising from meat-consumption and related activities are currently few and far between, with most attention falling on the agricultural stage of the food chain. There is a clear rationale for focusing on reducing the impacts of meat consumption in particular. This is particularly true of red meat, which has a highly disproportionate climate impact. Based on the background analysis done for this project so far on Norway's current policy, results point to multiple initiatives relating to environment and sustainability across the various players in the red meat and dairy food chain, but that they tend to be related to single and 'emblematic' issues - some of which work against each other, and do not go far enough, or fast enough to tackle climate change effectively. Meanwhile, consumer adoptions of environmental behaviours are also slow and focus on easy and convenient actions. In general, according to a recent DEFRA report, adopting a "low impact diet" was the action people were least likely to do out of twelve possible pro-environmental behaviours, even though they were able to make the changes easily. But since there is currently no vision of what a "sustainable diet" should be in Norway, it may be difficult for people to understand and act on what is meant by a "low impact diet". This is complicated by the crowded and often conflicting range of communications about diet in Norway, such healthwise that 'people are confused about what foods they can eat'

Next steps
If we assume at this early stage that some element of change is required in consumer behaviour, it is apparent that direct and indirect substitutes of meat need to be investigated. Additionally, there is a need to investigate further the alternative behaviours to meat consumption and what are the relevant and acceptable ones for the average Norwegian consumer. This will be the next step of the project in the understanding meat consumption in Norway. Another important point to look out for is the estimates that show that how different meat types (red meat, processed meat) in Norway account for CO2 emissions.

Contact persons:

Professor Christian A. Klöckner
Christian.Klockner @svt.ntnu.no

PostDoc Sunita Prugsamatz
sunita.prugsamatz@svt.ntnu.no

Professor Edgar Hertwich
edgar.hertwich@ntnu.no

- Most meats are NECESSITIES – income elasticity for chicken and fish are more inelastic than beef and pork.

- Since 1958/59, the annual consumption increased from 30.5 kg to 49.1 kg in the period 2005-2007 and was up to 77 kg per person in 2008.

- The consumer price index for food increased more than the total index. The vegetable group is the food group that has risen most in price in the years from 1997 to 2008.This may have an impact on how Norwegian meat eaters would view changing to a vegetarian diet, although it is still early to say how much contextual factors play a role here.

- The Norwegian Paradox: NOK 69 million spent every year on promoting Norwegian meat while only NOK 9 million is spent on promotion of fruit and vegetables, which are generally viewed as healthier food products than meat. This leads us to believe that there is a need to integrate nutritional and environmental messages, rather than have them compete. This we believe is a key argument when we propose the tailored information interventions for this project.

- Psycho-Demographic Variables – age differences are not very significant, 1970's generation are more 'fat-conscious', households with small children, consumers with high income and education, men vs. women (difference in the areas of health and food but differences are often mediated by other factors such as expert opinions and trust)

- From a health perspective, meat consumption in Norway is dependent on gender, age, BMI, smoking behaviours, education and total energy intake.

- Norwegian Women – Higher processed meat intake. Trend does show decline in meat intake especially among women with higher social status and education levels. For younger women, there is a negative effect on the consumption of red meat in Norway (however this could be substituted by their consumption of more processed foods and other factors)

- Numbers also show an increased trend among Norwegians, towards using the internet to get recipes, especially during the holiday seasons. For vegetarian dishes there seems to be more interest in using the internet in the last couple of years than ever before. This is a good sign for us as we wish to implement an interactive intervention platform for the project.

Multi-Regional Input-Output analyses - a powerful tool to assess environmental impact in global economy

The Industrial Ecology programme has been heavily involved in a number of research projects funded through EU's 7th Framework Programme this year. Most of these projects have focussed on the development and use of Multi-Regional Input-Output (MRIO) analysis. One of these projects, EXIOPOL, had its final conference in October 2011, with outcomes presented to over a hundred attendees from policy and academia. Keep an eye on www.exiobase.eu for database access.

At the same time a follow on project to EXIOPOL, CREEA (Compiling and Refining Environmental and Economic Accounts) began to get under way, with the kick-off meeting in Leiden in April. EXIOPOL and CREEA are projects aimed at using MRIO to develop world leading capability in analysis of environmental impacts across the global economy. The projects have unprecedented coverage of environmental impacts, allowing researchers and the public alike to more precisely trace the impact of their consumption to the source. How much land is used in Brazil to produce beef consumed in Britain can be answered by these projects. Off-shoring of industrial production has been a common theme for developed countries in recent years, and these MRIO projects are helping to account for this "leakage" of environmental impact.

From development to application

To facilitate practical use of the powerful MRIO databases for environmental policy-making, results should be condensed and translated to be readily understandable for actors outside the scientific community. As one of the partners in the OPEN:EU project (One Planet Economy Network: Europe), NTNU/IndEcol has developed a global MRIO-based model that can give environmental results in terms of a set of "footprint" indicators, including the Carbon, Water, and Ecological Footprint. These measure the amounts of greenhouse gas emissions, freshwater, and biologically productive land that are virtually embedded in consumed goods and services. Following the completion of the project in November 2011, a freely available online assessment tool has recently been launched, where users can browse a summary of the results and create their own scenarios about future development (see www.eureapa.net). Work is currently ongoing at IndEcol to publish detailed national assessments based on the model results.

From economy to technology

Many look to technology for the answer to our environmental problems. In PROSUITE (PROspective SUstainability Assessment of Technologies) NTNU is partnering with 25 other institutions in order to develop methods to assess the economic, environmental and social impacts of new technologies at full scale implementation. NTNU is adapting the MRIO outcomes of the EXIOPOL project to analyse new technologies in the global context. Individual technologies are assessed under different trajectories of implementation and under a number of scenarios of global development over the next 20 years. Sustainability assessment is then taken as a result of the properties of the future system – and what contributions these new technologies will have. Four new technologies are being assessed as part of the framework, with NTNU active in the Carbon Capture and Storage case study.

Contact persons:

Professor Edgar Hertwich,
edgar.hertwich@ntnu.no

Senior Researcher Richard Wood,
richard.wood@ntnu.no

PhD Candidate Kjartan Steen-Olsen,
kjartan.steen-olsen@ntnu.no

Researcher Jan Weinzettel,
jan.weinzettel@ntnu.no

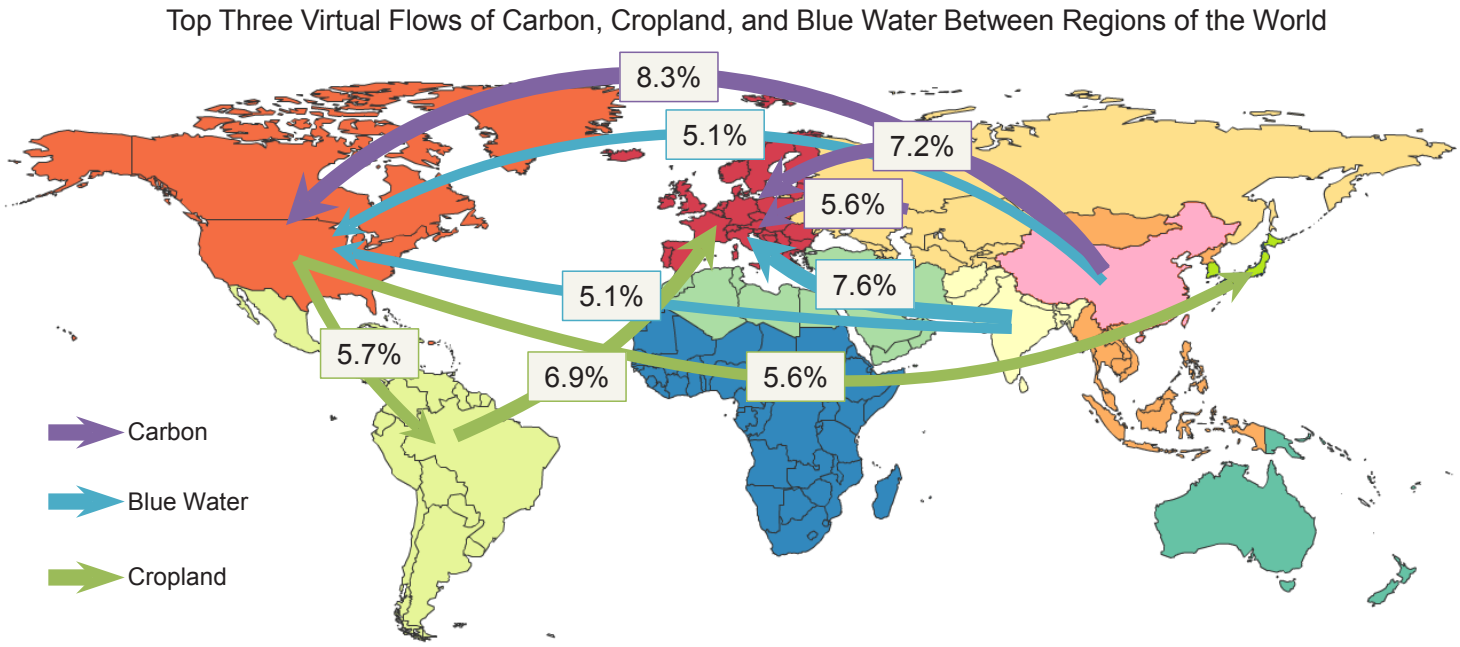


Figure: Flows of Carbon Footprint, Cropland Ecological Footprint and Blue Water Footprint virtually embodied in commodities traded between the countries of the world aggregated into 11 regions. The figure shows the three largest flows for each category. The start of an arrow indicate the region where the emissions (or the use of land or freshwater) occur, and the arrowhead points at the region where the final consumption of the end products occur. The value on each arrow represents the magnitude relative to the total footprint of each kind embodied in international trade (in percent).

Ambitious goals for Industrial Ecology at NTNU: Initiate a center of excellence in sociometabolic sustainability research

Climate mitigation requires radical changes in the size and structure of the material and energy flows in our society; the 'metabolism' of our society. Today CO2 emissions constitute society's largest output by mass. This obviously cannot continue if we are to avoid radical changes in the climate.

The question is how to do this without generating new problems. Many climate mitigation initiatives are based on the idea of reducing (fossil) energy consumption with e.g. better and more insulation of buildings. The emissions of CO2 from society will then be replaced by growing stocks of insulation, steel, plastic etc. embodied in structures and durable goods. The build-up of these stocks can cause other environmental and resource problems which may be real show-stoppers, e.g., land use issues of biofuels and biomaterials. The ultimate question is consequently whether this can solve the environmental problems we face.

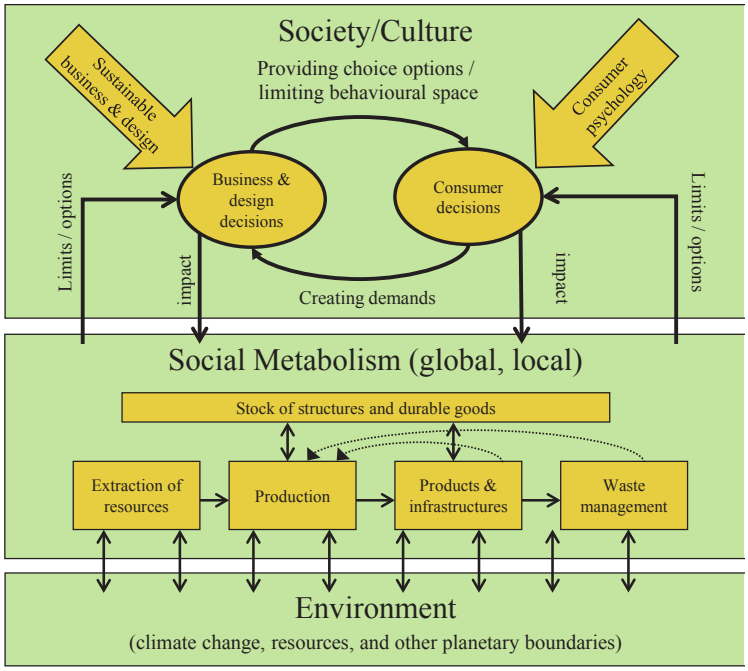
In order to put a more coordinated focus on these questions, the Industrial Ecology Programme has applied the Norwegian Research Council for funding for a center of excellence in sociometabolic sustainability research. The main goal for such a center will be to develop knowledge and tools essential for ensuring effective climate mitigation respecting the planetary boundaries. Prospective social metabolism must be systematic assessed and modeled where the functional connection of material and energy flows within our society and between society and nature are addressed.

The main hypothesis is that an understanding of society's metabolism will provide insights into the effectiveness, co-benefits and adverse impacts of climate change mitigation measures. Societal metabolism is an important, but yet little researched area; what are the functions and dynamics of the built environment and durable goods. A thorough understanding of the interaction between these stocks and consumption patterns will provide insights into new options for climate mitigation and into ways to increase the adoption of existing options.

Essential elements in enhancing climate mitigation will be to address consumer uptake, consumption pattern changes, and opportunities for material reuse and focus on the radical emissions reductions required for achieving the 2°C goal. An essential element in the research center will thus be to combine modeling of the metabolism with knowledge from social sciences on behavior and premises for behavior change.

Empirical research of stock-flow relationships and their interrelation to human behavior will inform model development and eventually model experimentation with potential future configurations of stocks and flows. At the core of this research is a integration of material flow, input-output and engineering approaches to modeling society's metabolism and a development of powerful tools for the acquisition and handling of data from statistical, geographical and remote sensing sources and the creation of an extensive data repository.

Technology adoption in society will be studied with agent-based models based on empirical surveys and laboratory experiments, and consumer environmental impacts will be assessed drawing on results from the urban and global sociometabolic models. New methods of 'design for sustainable behavior' will be developed to integrate sociometabolic considerations in product design and its adoption by business.



The figure shows how the social metabolism constitutes the physical realization of our society. It requires inputs from nature in terms of energy and material resources, it occupies areas, and it inevitably results in solid, liquid or gaseous wastes. 'Environmental externalities' constitute hence not an occasional problem that is easily corrected, but a systemic feature of every economic activity. It is therefore essential to strive for a social metabolism that is compliant with the planetary boundaries. Social sciences commonly focus exclusively on the immaterial aspects of society, the human relationships, institutional arrangements and individual behavior, and the symbolic value of material goods. The social metabolism as a binding layer is important because it ultimately serves to sustain this culture, and these cultural aspects of society are important because they exert control over the metabolism, to the degree that this is physically possible

In the figur, impacts on the environment emerge as a result of the flows and conversion processes of material and energy and the transformation of land, i.e., at the interface of the society's metabolism and the environment. In order to understand the utilization of nature by society, we need to understand the flow of materials and energy through this social metabolism and the utility of these flows for and their control by society and its actors.

Main results for this research will thus be:

- new techniques to model the physical dimension of the economy with a specific focus on the composition and function of stocks of structures and durable goods;
- modeling results providing insights to global development options including the large-scale deployment of mitigation technologies;
- the analysis of options to change household technologies and consumption patterns given their mutual interaction and a development of some of these options through design methodology.

Peer-reviewed journal publications

1. Arvesen, A. and E. G. Hertwich. 2011. Environmental implications of large-scale adoption of wind power: a scenario-based life cycle assessment. Environmental Research Letters 6(4): 045102.
2. Arvesen, A., R. M. Bright, and E. G. Hertwich. 2011. Considering only first-order effects? How simplifications lead to unrealistic technology optimism in climate change mitigation. Energy Policy 39(11): 7448-7454.
3. Bright, R. M., A. H. Strømman, and G. P. Peters. 2011. Radiative forcing impacts of boreal forest biofuels: A scenario study for Norway in light of albedo. Environmental Science and Technology 45(17): 7570-7580.
4. Carson, S. G., A. M. Fet, and C. Skaar. 2011. A Nordic Perspective of Corporate Social Responsibility (CSR). Etikk i praksis 2011(1): 1-7.
5. Cherubini, F. and A. H. Strømman. 2011a. Chemicals from lignocellulosic biomass: opportunities, perspectives, and potential of biorefinery systems. Biofuels, Bioproducts and Biorefining 5(5): 548-561.
6. Cherubini, F. and A. H. Strømman. 2011b. Life cycle assessment of bioenergy systems: State of the art and future challenges. Bioresource Technology 102(2): 437-451.
7. Cherubini, F., A. H. Strømman, and E. Hertwich. Effects of boreal forest management practices on the climate impact of CO2 emissions from bioenergy. Ecological Modelling.
8. Cherubini, F., A. H. Strømman, and S. Ulgiati. 2011a. Influence of allocation methods on the environmental performance of biorefinery products - A case study. Resources, Conservation and Recycling 55(11): 1070-1077.
9. Cherubini, F., G. P. Peters, T. Berntsen, A. H. Strømman, and E. Hertwich. 2011b. CO2 emissions from biomass combustion for bioenergy: atmospheric decay and contribution to global warming. GCB Bioenergy 3(5): 413-426.
10. Drugli, M. B., C. Kløckner, and B. S. Larsson. 2011. Do demographic factors, school functioning, and quality of student-teacher relationships as rated by teachers predict internalising and externalising problems among Norwegian school children? Evaluation and research in education 24(4): 243-254.
11. Fermann, G. 2011. Strategisk ledelse og utenrikspolitisk krisehåndtering. Stat og styring(3): 15-19.
12. Fet, A., O. Michelsen, and L. Boer. 2011. Green public procurement in practice - The case of Norway. Society and Economy 33(1): 183-198.
13. Govindarajan, V. and C. Heng. 2011. Malaysian Water Tariff Influences Water-saving Habits. Journal - American Water Works Association 103(7): 32-34.
14. Govindarajan, V., M. Didi, and A. Mujthaba. 2011. Male makes the most of its limited land and freshwater. Journal - American Water Works Association 103(5): 44-50.
15. Guest, G., R. M. Bright, F. Cherubini, O. Michelsen, and A. H. Strømman. Life Cycle Assessment of Biomass-based Combined Heat and Power Plants: Centralized Versus Decentralized Deployment Strategies. Journal of Industrial Ecology.
16.. Hertwich, E. G. 2011. The Life Cycle Environmental Impacts Of Consumption. Economic Systems Research 23:27-47.
17. Hertwich, E. G. and C. Roux. 2011. Greenhouse gas emissions from the consumption of electric and electronic equipment by Norwegian households. Environmental Science and Technology 45(19): 8190-8196.
18. Holgersen, K. H., C. Kløckner, H. J. Bøe, L. Weisæth, and A. Holen. 2011. Disaster Survivors in Their Third Decade: Trajectories of Initial Stress Responses and Long-Term Course of Mental Health. Journal of Traumatic Stress 24(3): 334-341.
19. Huijbregts, M. A. J., S. Hellweg, and E. Hertwich. 2011. Do we need a paradigm shift in life cycle impact assessment? Environmental Science and Technology 45(9): 3833-3834.
20. Johannesen, A. B. and A. Skonhoft. 2011. Livestock as Insurance and Social Status: Evidence from Reindeer Herding in Norway. Environmental and Resource Economics 48(4): 679-694.
21. Kastner, I., E. Matthies, and M. Willenberg. 2011. Chancen zur Förderung nachhaltigkeitsrelevanter Investitionsentscheidungen durch psychologisch basiertes Framing – eine Pilotstudie. Umweltpsychologie 15(1): 30-51.
22. Klöckner, C. and T. Friedrichsmeier. 2011. A multi-level approach to travel mode choice - How person characteristics and situation specific aspects determine car use in a student sample. Transportation Research Part F: Traffic Psychology and Behaviour 14(4): 261-277.
23. Klöckner, C. and E. B. Matthies. 2011. Two Pieces of the Same Puzzle? Script Based Car Choice Habits Between the Influence of Socialization and Past Behavior. Journal of Applied Social Psychology.
24. Klöckner, C. and I. O. Oppedal. 2011. General vs. domain specific recycling behaviour—Applying a multilevel comprehensive action determination model to recycling in Norwegian student homes. Resources, Conservation and Recycling 55(4): 463-471.
25. Laitala, K. M., C. Boks, and I. G. Klepp. 2011. Potential for environmental improvements in laundering. International Journal of Consumer Studies 35(2): 254-264.
26. Larsen, H. N. and E. G. Hertwich. 2011. Analyzing the carbon footprint from public services provided by counties. Journal of Cleaner Production 19(17-18): 1975-1981.
27. Larsen, H. N., J. Pettersen, C. Solli, and E. G. Hertwich. Investigating the Carbon Footprint of a University - The case of NTNU. Journal of Cleaner Production.
28. Lindstad, H., B. E. Asbjørnslett, and A. H. Strømman. 2011. Reductions in greenhouse gas emissions and cost by shipping at lower speeds. Energy Policy 39(6): 3456-3464.
29. Liu, G., C. E. Bangs, and D. B. Müller. 2011. Unearthing Potentials for Decarbonizing the U.S. Aluminum Cycle. Environmental Science & Technology 45(22): 9515-9522.
30. Majeau-Bettez, G., T. R. Hawkins, and A. H. Strømman. 2011a. Life cycle environmental assessment of lithium-ion and nickel metal hydride batteries for plug-in hybrid and battery electric vehicles. Environmental Science and Technology 45(10): 4548-4554.
31. Majeau-Bettez, G., A. H. Strømman, and E. G. Hertwich. 2011b. Evaluation of process- and Input-Output-based Life CycleInventory Databases with Regards to Truncation and Aggregation Issues. Environmental Science & Technology: forthcoming.
32. Majeau-Bettez, G., T. R. Hawkins, and A. H. Strømman. 2011c. Erratum: Life cycle environmental assessment of lithium-ion and nickel metal hydride batteries for plug-in hybrid and battery electric vehicles (Environmental Science & Technology (2011) 45 (4548-4554) DOI: 10.1021/es103607c). Environmental Science and Technology 45(12): 5454.
33. Michelsen, O., A. O. Syverhuset, B. Pedersen, and J. I. Holten. 2011. The impact of climate change on recent vegetation changes on Dovrefjell, Norway. Diversity 3: 91-111.
34. Müller, D. B., T. Wang, and B. Duval. 2011. Patterns of iron use in societal evolution. Environmental Science and Technology 45(1): 182-188.
35. Nordby, A. S. 2011a. Carbon reductions and building regulations: the case of Norwegian mountain cabins. Building Research and Information 39(6): 553-565.
36. Nordby, A. S. 2011b. Etterlysning: miljøregnskap for ventilasjonsanlegg. Arkitektur N(3): 130-133.
37. Nævdal, E., J. O. Olussen, and A. Skonhoft. A bioeconomic model of trophy hunting. Ecological Economics.
38. Olaussen, J. O. and A. Skonhoft. 2011. A cost-benefit analysis of moose harvesting in Scandinavia. A stage structured modelling approach. Resource and Energy Economics 33(3): 589-611.
39. Sandberg, N. H., H. Bergsdal, and H. Brattebø. 2011. Historical energy analysis of the Norwegian dwelling stock. Building Research and Information 39(1): 1-15.

40. Singh, B., A. H. Strømman, and E. Hertwich. 2011a. Life cycle assessment of natural gas combined cycle power plant with post-combustion carbon capture, transport and storage. International Journal of Greenhouse Gas Control 5(3): 457-466.
41. Singh, B., A. H. Strømman, and E. G. Hertwich. 2011b. Comparative life cycle environmental assessment of CCS technologies. International Journal of Greenhouse Gas Control 5(4): 911-921.
42. Singh, B., A. H. Strømman, and E. G. Hertwich. 2011c. Comparative impact assessment of CCS portfolio: Life cycle perspective. Energy Procedia 4: 2486-2493.
43. Skaar, C. and A. M. Fet. Accountability in the Value Chain: From Environmental Product Declaration (EPD) to CSR Product Declaration. Corporate Social Responsibility and Environmental Management.
44. Skonhoft, A., N. Vestergaard, and M. Quaas. 2011. Optimal Harvest in an Age Structured Model with Different Fishing Selectivity. Environmental and Resource Economics: 1-20.
45. Sopha, B. M. and C. A. Klöckner. 2011. Psychological factors in the diffusion of sustainable technology: A study of Norwegian households' adoption of wood pellet heating. Renewable and Sustainable Energy Reviews 15(6): 2756-2765.
46. Sopha, B. M., C. A. Klöckner, and E. G. Hertwich. 2011a. Adopters and non-adopters of wood pellet heating in Norwegian households. Biomass and Bioenergy 35(1): 652-662.
47. Sopha, B. M., C. A. Klöckner, and E. G. Hertwich. 2011b. Exploring policy options for a transition to sustainable heating system diffusion using an agent-based simulation. Energy Policy 39(5): 2722-2729.
48. Sparrevik, M., T. Saloranta, G. Cornelissen, E. Eek, A. M. Fet, G. D. Breedveld, and I. Linkov. 2011. Use of life cycle assessments to evaluate the environmental footprint of contaminated sediment remediation. Environmental Science and Technology 45(10): 4235-4241.
49. Tukker, A. 2011. Harmonizing science and policy programs for a decent and sustainable life for all by the mid-millennium. Journal of Industrial Ecology 15(5): 652-654.
50. Tukker, A., R. A. Goldbohm, A. De Koning, M. Verheijden, R. Kleijn, O. Wolf, I. Pèrez-Domìnguez, and J. M. Rueda-Cantuche. 2011. Environmental impacts of changes to healthier diets in Europe. Ecological Economics 70(10): 1776-1788.
51. Ulgiati, S., M. Ascione, S. Bargigli, F. Cherubini, P. P. Franzese, M. Raugei, S. Viglia, and A. Zucaro. 2011. Material, energy and environmental performance of technological and social systems under a Life Cycle Assessment perspective. Ecological Modelling 222(1): 176-189.
52. Veltman, K., M. A. J. Huijbregts, H. Rye, and E. G. Hertwich. 2011. Including Impacts of Particulate Emissions on Marine Ecosystems in Life Cycle Assessment: The Case of Offshore Oil and Gas Production. Integrated Environmental Assessment and Management 7(4): 678-686.
53. Venkatesh, G. 2011. Interpreting sustainability using Robert Pirsig's levels of quality. Problemy Ekorozwoju 6(2): 63-66.
54. Venkatesh, G. and H. Brattebø. 2011a. Environmental impact analysis of chemicals and energy consumption in wastewater treatment plants: Case study of Oslo, Norway. Water Science and Technology 63(5): 1018-1031.
55. Venkatesh, G. and H. Brattebø. 2011b. Energy consumption, costs and environmental impacts for urban water cycle services: Case study of Oslo (Norway). Energy 36(2): 792-800.
56. Venkatesh, G. and H. Brattebø. 2011c. Case study: Analysis of chemicals and energy consumption in water and wastewater treatment, as cost components: Case study of Oslo, Norway. Urban Water Journal 8(3): 189-202.
57. Venkatesh, G., J. Hammervold, and H. Brattebø. 2011. Methodology for determining life-cycle environmental impacts due to material and energy flows in wastewater pipeline networks: A case study of Oslo (Norway). Urban Water Journal 8(2): 119-134.
58. Weinzettel, J. and J. Kovanda. 2011. Structural Decomposition Analysis of Raw Material Consumption. Journal of Industrial Ecology 15(6): 893-907.
59. Weinzettel, J., M. Havrànek, and M. Šč asný. A consumption-based indicator of the external costs of electricity. Ecological Indicators.
60. Wolf, O., I. Pèrez-Domìnguez, J. M. Rueda-Cantuche, A. Tukker, R. Kleijn, A. de Koning, S. Bausch-Goldbohm, and M. Verheijden. 2011. Do healthy diets in Europe matter to the environment? A quantitative analysis. Journal of Policy Modeling 33(1): 8-28.

Accredited conference proceedings and book chapters

1. Aschehoug, Silje Helene; Boks, Casper.
Success Criteria For Implementing Sustainability Information In Product Development. I: Proceedings of the 18th International Conference on Engineering Design (ICED11), 15-18 Aug 2011. The Design Society 2011 ISBN 978-1-904670-32-2. s. 145-154
2. Aryana, B., C. Boks, and A. Navabi. 2011. Possibilities for cultural customization of mobile communication devices: The case of iranian mobile users. In Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). Orlando, FL.
3. Beisenkamp, A., C. Klöckner, and S. Hallmann. 2011. Voraussetzungen für eine gute Kinderheit aus Kindersicht. In Kinder in Deutschland. Eine Bilanz empirischer Studien: Juventa Verlag.
4. Boks, C. 2011. Design for Sustainable Behaviour Research Challenges. In Design for Innovative Value Towards a Sustainable Society. Proceedings of Ecodesign 2011: 7th International Symposium on Environmentally Conscious Design and Inverse Manufacturing: Springer.
5. Boks, C., R. Wever, and A. Stevels. 2011. State-of-the-art Ecodesign on the Electronics Shop Shelves? A Quantitative Analysis of Developments in Ecodesign of TV Sets. In Glocalized Solutions for Sustainability in Manufacturing: Proceedings of the 18th CIRP International 173 Conference on Life Cycle Engineering, Technische Universität Braunschweig, Braunschweig, Germany, May 2nd - 4th, 2011: Springer.
6. Klöckner, C. 2011. Towards a psychology of climate change. In The economic, social, and political elements of climate change: Springer.
7. Laitala, Kirsi Maria; Boks, Casper; Klepp, Ingun Grimstad. Potential for environmental improvements in laundering. International Journal of Consumer Studies 2011 ;Volum 35.(2) s. 254-264
8. Schmalz, J. and C. Boks. 2011. Simultaneous Application of Design for Sustainable Behavior and Linked Benefit Strategies in Practice. In Glocalized Solutions for Sustainability in Manufacturing: Proceedings of the 18th CIRP International 173 Conference on Life Cycle Engineering, Technische Universität Braunschweig, Braunschweig, Germany, May 2nd - 4th, 2011: Springer.
9. Verhulst, E. and C. Boks. 2011. Sustainable design strategies in practice and their influence on business models. In Design for Innovative Value Towards a Sustainable Society. Proceedings of Ecodesign 2011: 7th International Symposium on Environmentally Conscious Design and Inverse Manufacturing: Springer.
10. Wigum, K. S., J. Zachrisson, and C. Boks. 2011. The role of product and system interfaces in designing zero emission buildings. Paper presented at Proceedings of the 2011 IEEE International Symposium on Sustainable Systems and Technology, ISSST 2011, Chicago, IL.
11. Zachrisson, J. and C. Boks. 2011. A framework for selecting sustainable behavior design strategies. Paper presented at Proceedings of the 2011 IEEE International Symposium on Sustainable Systems and Technology, ISSST 2011, Chicago, IL.
12. Zachrisson, J. L. D., G. Storrø, and C. Boks. 2011. Using a guide to select design strategies for behaviour change; Theory vs. Practice. In Design for Innovative Value Towards a Sustainable Society. Proceedings of Ecodesign 2011: 7th International Symposium on Environmentally Conscious Design and Inverse Manufacturing: Springer.

Christmas Party 2011

Industrial Ecology Programme (IndEcol)
Norwegian University of Science and Technology (NTNU)
NO - 7491 Trondheim
Tel: +47 73 59 89 40
Fax: +47 73 59 89 43
E-mail: indecol@indecol.ntnu.no
Web: www.ntnu.edu/indecol

For a full publication list, or to download IndEcol reports or working papers, please visit our web site: www.ntnu.edu/indecol