Centre for Sustainable Energy Studies

Nurturing new technologies

CenSES report

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

Nurturing new technologies – CenSES report

This report is based on a position paper which summarises a CenSES user case conducted within the scope of the research area on *Innovation, commercialization and public engagement*. The key topic is development of upstream renewable energy (RE) technologies *in* Norway or *involving* Norwegian actors. The position paper was developed with input from CenSES user partners from three dedicated workshops.
For author list, full scientific elaboration and references, we refer to the original document.

ISBN: 978-82-93198-33-8

Table of Contents

Introduction

It is vital for the transformation of global energy systems to develop, diffuse and upscale new renewable energy (RE) production technologies. New technologies are needed in the transport and building sectors, to improve energy system functioning (e.g. smart grids) and to enhance energy efficiency or contribute to reducing GHG[i1] emissions (e.g. CCS). There is no silver bullet to enable a global sustainable supply of energy to mankind[2] , but rather a combination of many technologies and user practices working in tandem to bring us closer to that goal. The process of developing and implementing new technologies and solutions for more sustainable energy systems requires various types of nurturing, like market support and R&D stimuli.

Countries differ immensely in their energy systems, in their natural resource endowments, and in their knowledge bases and pre-existing industrial capacities for developing new clean energy technologies. Norway differs from most other European countries in terms of prospects, needs and rationales for changing its energy system. Norway's large-scale hydropower production capacity implies limited needs for added RE production, at least in the short- to mid-term. Therefore, the rationales for developing and deploying RE technology may be weaker than in many other countries. Developing RE technology and related value-adding activities are nonetheless key aims of the Norwegian strategy for research, development, demonstration and commercialisation of new energy technology[3].

Why nurture new technologies?

Technological innovations in large socio- technical systems, such as energy and transport, may be promising (in providing e.g. efficiency gains or environmental benefits), but their performance at conception and early development phases tends to be poor compared to existing technologies.

Evolutionary perspectives on socio-technical change emphasise the co-evolution of technologies, institutions, regulations, infrastructure and social practices, resulting in rather rigid socio-technical systems that often provide few opportunities for new technologies. any new technologies require either substantial systemic change or the formation of new systems.

The struggle between 'old' and 'new' is particularly forceful in energy systems, which are large, complex and slow to change. The development of such systems tends to be path-dependent: decisions and investments made in the past have a strong impact on subsequent development phases[4]. The transition from fossil to 'clean' energy solutions is encumbered by huge investments in equipment, infrastructure, rules, routines and policies in established systems that have aligned and optimised over time. Such established systems are often conceptualized as 'regimes' which form the institutional context for technological and economic practices, problem-solving and strategic decision making within an industry[5]. Institutions (rules, norms, routines, practices) guide technological

[1] GHG = Greenhouse Gas

[2] LOVIO, R., MICKWITZ, P. & HEISKANEN, E. 2011. Path dependence, path creation and creative destruction in the evolution of energy systems. *In:* WÜSTENHAGEN, R. & WUEBKER, R. (eds.) *Handbook of Research on Energy Entrepreneurship.* Cheltenham: Edward Elgar. IPC, 2014

[3] ENERGI21 2014. Strategi 2014. Oslo: Energi21

[4] Lovio et al., 2011

[5] GEELS, F. W. 2010. Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective. *Research Policy,* 39**,** 495-510; FUENFSCHILLING, L. & TRUFFER, B. 2014. The structuration of socio-technical regimes—Conceptual foundations from institutional theory. *Research Policy,* 43**,** 772-791.

development, resulting primarily in incremental innovations that steer technological evolution along a pre-defined path rather than alternative ones. Because of their inconformity in established socio-technical energy systems, new energy solutions require support, nurturing.

The Latin word *nutritura* has several connotations – such as feeding, nourishing, training, educating, protecting – that are all relevant for understanding how technological innovations develop. Nurturing refers to deliberate acts by social actors to support the development of new technologies. We see technologies as social phenomena; they are never given, they do not decide for themselves, nor do they have inner powers that drive them towards predetermined end states. It is not sufficient to invent new energy technologies – technological development, implementation and diffusion hinges on a number of processes and mechanisms that contribute to knowledge development, legitimation, resource mobilisation and utilisation, and the development of externalities and complementary assets (e.g. infrastructure). The failure or success of wind turbines, solar panels, district heating systems or other new technologies that are required to enable sustainable energy systems cannot be explained by reference to technological aspects or classical market forces alone[6].

Risks and costs for environmental innovations are borne by the innovator, whereas the benefits (such as less pollution) are reaped by society. This double externality problem may reduce incentives for environmental innovation[7], providing a key rationale for policy support that stimulates innovation.

The alterations necessary for sustainable energy systems primarily change production and distribution systems rather than end-products: even if 'clean' fuels and technologies replace fossil-based solutions, energy service end products (energy, heat) largely remain unchanged[8]. In choosing between renewable energy and non-renewable energy, consumers thus have little to compare with other than price – an electron is an electron regardless of whether it stems from a solar PV panel or a coal plant. This is very different from most other commodities or consumer goods where the benefits of a new product (e.g. a new type of mobile phone) are far more obvious to the consumer. Energy industries are as such producer-driven, and given vested interests in sunk costs, the incentives for established actors to change course may be small.

So, new renewable energy technologies require nurturing because

- established energy systems are rigid, and selection environments favour mature technologies
- technological development in emerging industries is a lengthy, highly risk-prone and capital-intensive process
- new technologies often require the build-up of new or adapted complementary resources, infrastructures, practices and institutions
- in addition to classical market failure, environmental innovation confronts the 'double-externality' problem which reduces incentives to invest
- end-use demand for clean energy does not drive innovation in the same way as it does in many other industries (e.g. consumer electronics)

---

[6] e.g. SØRENSEN, K. 2013. Beyond innovation. Towards an extended framework for analysing technology policy. *Nordic Journal of Science and Technology Studies,* 1**,** 12-23.

[7] BEISE, M. & RENNINGS, K. 2005. Lead markets and regulation: a framework for analyzing the international diffusion of environmental innovations. *Ecological Economics,* 52**,** 5-17.

[8] Lovio et al., 2011

Technologies in a formative phase require policy interventions that create protective spaces or ‘technological niches’ where technology can be developed alongside learning processes involving different types of actors and stakeholders. (e.g. R&D projects, pilot/demonstration programs, subsidized market mechanisms) shielding them from constraints and selection pressures in established free markets[9]. Niches can take many forms, ranging from publicly funded electricity markets to in-house development projects in large corporations, and they can involve various types of policy instruments that nurture innovation processes and empower new technologies vis-a-vis established technologies.

Nurturing new technologies: innovation processes and support

The development of new RE technologies requires a mix of supportive policy instruments., Technological change in the sustainability context "*...is faced with multiple market, system and institutional failures and thus requires multi-faceted policy interventions*."[10]

This broad approach counters so-called market failure approaches, which are commonly applied in addressing grand challenges such as climate change[11]. The rationale of market failure approaches is that investment in R&D makes new technologies more efficient. When new technologies have matured sufficiently, they can compete in the market with existing technologies.

While the market failure approach may provide a general rationale for government involvement and use of policy tools to address transition challenges, the approach has been argued to not provide precise design options[12] because of the way innovation and diffusion rely on a number of sub-processes of which knowledge development through R&D is but one.

R&D alone does not drive innovation. The crucial role of public policies affecting demand is not only linked to driving sufficiently rapid and widespread adoption of alternative-energy technologies, but also impacts the development process itself. User side factors were highly important in the development of some of the large-scale innovation programs coupled to IT, semiconductors and agriculture.[13] Development of these key innovations took place not only on the basis of knowledge development through R&D, but also by deep public sector involvement that enabled an articulation of demand – i.e. stimulating inclusion of user side dynamics in nurturing emerging technologies. Moreover, within a broader field of R&D support, the mix of different types of support has been deemed necessary. Meeting highly complex societal challenges, such as climate change, requires a broad mix of R&D support programmes both for specific needs and demands (typically near-term) and support of basic research yielding benefits mainly in the long-term.[14] The necessary mix of support measures typically targets both push and pull mechanisms.[15]

---

[9] SMITH, A. & RAVEN, R. 2012. What is protective space? Reconsidering niches in transitions to sustainability. *Research Policy,* 41**,** 1025-1036.

[10] ROGGE, K. S. & REICHARDT, K. 2016. Policy mixes for sustainability transitions: An extended concept and framework for analysis. *Research Policy,* 45**,** 1620-1635

[11] NILL, J. & KEMP, R. 2009. Evolutionary approaches for sustainable innovation policies: From niche to paradigm? *Research Policy,* 38**,** 668-680

[12] METCALFE, S. & GEORGHIOU, L. 1997. Equilibrium and evolutionary foundations of technology policy. *CRIC Discussion Papers.* Centre for Research on Innovation and Competition

[13] MOWERY, D. C., NELSON, R. R. & MARTIN, B. R. 2010. Technology policy and global warming: Why new policy models are needed (or why putting new wine in old bottles won’t work). *Research Policy,* 39**,** 1011-1023

[14] Mowery et al. 2010

[15] Rogge and Reichardt, 2016

Some countries, such as the Netherlands, have focused their policy support on the early phases of the innovation process, i.e. promoted a 'technology push' policy. Without sufficient support in the market or near-to-market segments of the innovation journey, many RE technologies became *"stuck in the R&D or early demonstration stage, unable to move into pre-commercial trials"*[16]. As we will see, this has also been a challenge for new RE technology in Norway.

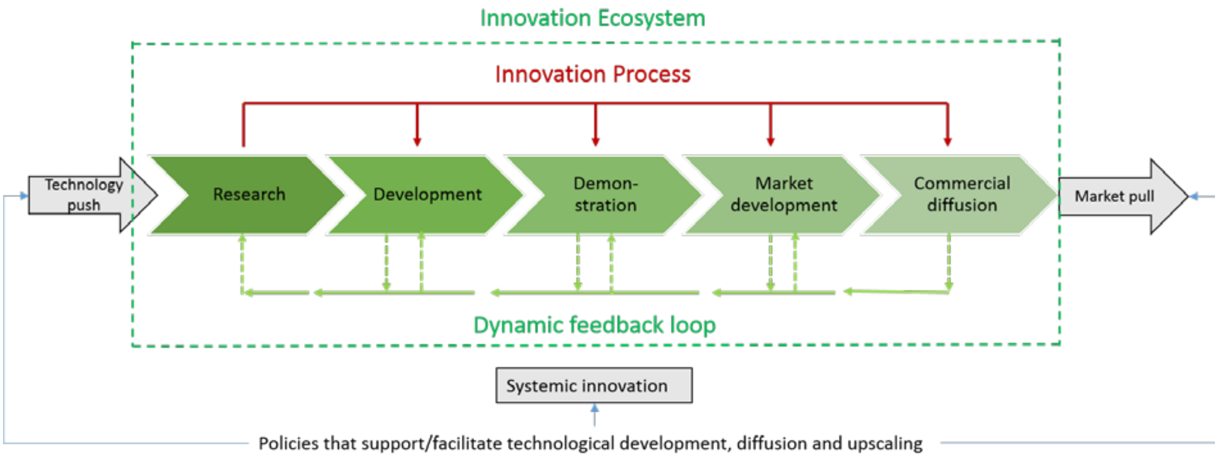


FIGURE 1 INNOVATION PROCESSES WITHIN THE INNOVATION ECOSYSTEM[17]

Figure 1 illustrates the interactive nature of innovation processes as technological development progresses through various stages. All these stages are relevant in a nurturing context. Specific policy instruments are categorized as push and pull policies[18]. Technology push refers to R&D funding and other support mechanisms targeting technological development such as basic R&D tied to a specific technology, or resources for pilots and demonstrations. Market pull refers to support mechanisms aiming to create and support markets for particular technologies. Push and pull support are important for the development and diffusion of new RE technologies because successful development, deployment and implementation of new RE depends on the co-evolution of technologies, industries and markets. Figure 2 from IPCC's report on renewable energy illustrates how the 'technology cycle' and the 'market cycle' mutually not only reinforce each other – the two are both necessary for industry development around new RE technologies.

[16] NEGRO, S. O., ALKEMADE, F. & HEKKERT, M. P. 2012. Why does renewable energy diffuse so slowly? A review of innovation system problems. *Renewable and Sustainable Energy Reviews,* 16**,** 3836-3846

[17] Expanded from IRENA 2015. Renewable Energy Technology Innovation Policy: A Process Development Guide.

[18] IPCC, 2012;

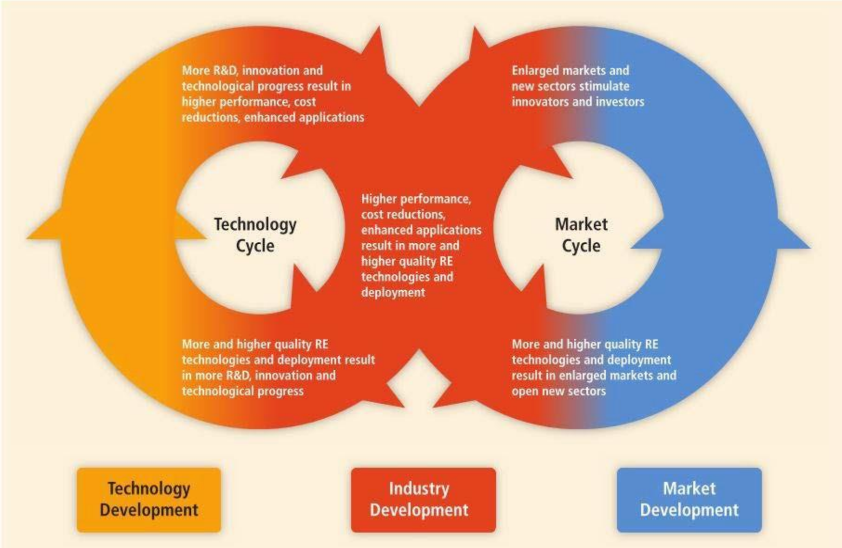


FIGURE 2 THE MUTUALLY REINFORCING CYCLES OF TECHNOLOGY DEVELOPMENT AND MARKET DEPLOYMENT[19]

Nurturing new technologies: key functions

Innovation systems need to form around new technologies. National (and regional/local) regulations and policy instruments have a strong impact on their development. This development is conditioned by a set of key functions[20] whereby resources are developed, mobilised and/or attracted, and self-reinforcing mechanisms associated with technological and industrial development gain momentum (or not). This provides a framework for assessing the strengths and weaknesses of the innovation systems that form the development context for new technologies.

We distinguish between four key resource formation processes: *knowledge*, *niche markets*, *financial and human capital,* and *legitimacy.*[21] The most studied RE technology/industry within the scope of RA4[22] is offshore wind power.

- **Knowledge creation**: activities that create new technological knowledge and related competencies, e.g. learning by searching, learning by doing, activities that lead to information exchange among actors, learning by interacting and learning by using networks.

- **Niche market formation**: activities that contribute to the creation of protected space for the new technology, and construction of new market segments.

- **Financial and human capital**: activities related to the mobilisation and allocation of financial and human resources.

---

[19] **FROM IPCC 2012**

[20] BERGEK, A., HEKKERT, M. P. & JACOBSSON, S. 2008a. Functions in innovation systems: A framework for analyzing energy-system dynamics and identifying goals for system-building activities by entrepreneurs and policymakers. *In:* FOXON, T. J., KÖHLER, J. & OUGHTON, C. (eds.) *Innovation for a Low Carbon Economy. Economic, Institutional and Management Approaches.* Cheltenham: Edward Elgar.

[21] This is a simplified take on the functions of technological innovation systems approach as suggested by Bergek et al. 2008, see also Hekkert et al. 2007.

[22] RA4: SenCES Research Area 4 on Innovation, commercialisation and public involvement

- **Technological legitimacy and social acceptance**: activities that embed a new technology in existing institutional structures, adapt the institutional environment to the needs of the technology, activities that promote social acceptance.

Knowledge creation

Learning and new combinations of knowledge form a central dimension for nurturing new technologies. Knowledge creation includes both scientific knowledge and knowledge arising from use, trial and error associated with production. The direct impact of public research is less important than knowledge originating from interaction with users, suppliers and learning from internal manufacturing.[23] While traditional economic approaches focus heavily on knowledge generation through R&D, processes of knowledge development have multiple sources such as learning from use, experience and imitation. Innovation should be seen as an interactive process encompassing a range of actors and multiple feedback mechanisms (cf. Figure 2). Pure 'technology push' strategies have limitations in terms of innovation effects.

R&D can play a key role as a problem solver through the interaction between university and industry, which enables the integration of R&D with non-R&D aspects of innovation. The active pursuit of developing new products and services can trigger new bottlenecks and problems where R&D can play a key problem-solving role.

Due to increasing global competition, stricter regulations, lack of funding, uncertain market demand, and complex technologies, many firms can no longer afford to innovate on their own[24]. Innovation is both an individual and collective act, which has formed the basis for thinking about innovation as a systemic phenomenon involving direct and indirect interaction between actors and institutions.[25] Firms in a wide range of industries are therefore involved in some form of inter-organisational collaboration which is increasingly obtained through external collaboration with universities and public research organizations, so-called university-industry collaboration. This way, firms can source novel knowledge and technologies and participate in innovation projects that they would not have been able to run in their own capacity. Hence, research has emphasised the contribution of university-industry collaboration with regards to higher productivity, regional development and renewal of industry.

[23] COHEN, W. M., NELSON, R. R. & WALSH, J. P. 2002. Links and impacts: The influence of public research on industrial R&D. *Management science,* 48

[24] VAN DE VRANDE, V., DE JONG, J. P. J., VANHAVERBEKE, W. & DE ROCHEMONT, M. 2009. Open innovation in SMEs: Trends, motives and management challenges. *Technovation,* 29**,** 423- 437

[25] HEKKERT, M. P., SUURS, R. A. A., NEGRO, S. O., KUHLMANN, S. & SMITS, R. E. H. M. 2007. Functions of innovation systems: A new approach for analysing technological change. *Technological Forecasting and Social Change,* 74**,** 413-432

Knowledge creation

Learning and new combinations of knowledge form a central dimension for nurturing new technologies. Knowledge creation includes both scientific knowledge and knowledge arising from use, trial and error associated with production. The direct impact of public research is less important than knowledge originating from interaction with users, suppliers and learning from internal manufacturing.[26] While traditional economic approaches focus heavily on knowledge generation through R&D, processes of knowledge development have multiple sources such as learning from use, experience and imitation. Innovation should be seen as an interactive process encompassing a range of actors and multiple feedback mechanisms (cf. Figure 2). Pure 'technology push' strategies have limitations in terms of innovation effects.

R&D can play a key role as a problem solver through the interaction between university and industry, which enables the integration of R&D with non-R&D aspects of innovation. The active pursuit of developing new products and services can trigger new bottlenecks and problems where R&D can play a key problem-solving role.

Due to increasing global competition, stricter regulations, lack of funding, uncertain market demand, and complex technologies, many firms can no longer afford to innovate on their own[27]. Innovation is both an individual and collective act, which has formed the basis for thinking about innovation as a systemic phenomenon involving direct and indirect interaction between actors and institutions.[28] Firms in a wide range of industries are therefore involved in some form of inter-organisational collaboration which is increasingly obtained through external collaboration with universities and public research organizations, so-called university-industry collaboration. This way, firms can source novel knowledge and technologies and participate in innovation projects that they would not have been able to run in their own capacity. Hence, research has emphasised the contribution of university-industry collaboration with regards to higher productivity, regional development and renewal of industry.[29]

CenSES research on knowledge creation

Regarding new RE production technologies, nurturing efforts through policy instruments in Norway have provided relatively ample resources to R&D, the 'technology push' side of the innovation process.[30] However, in the absence of a more coherent policy mix involving also technology pull instruments, the outcome of this R&D strategy has been limited.

CenSES research in the more downstream segments of the energy system has also recognised the importance of knowledge creation for new innovations. Smart grids are an important element in energy systems with high levels of intermittent power production technologies. CenSES researched

[26] COHEN, W. M., NELSON, R. R. & WALSH, J. P. 2002. Links and impacts: The influence of public research on industrial R&D. *Management science,* 48
[27] van de Vrande et al., 2009
[28] Hekkert et al., 2007
[29] LAURSEN, K. & SALTER, A. 2004. Searching high and low: what types of firms use universities as a source of innovation? *Research Policy,* 33**,** 1201-1215
[30] HANSON, J. 2013. *Dynamics of innovation systems for renewable energy technology: the role of post-introduction improvements.* Ph.D., University of Oslo

have analysed four smart grid demonstration projects in Norway.[31] The result highlights the importance of large-scale demonstration sites as arenas for social learning, where technologies are developed in interaction with different types of pre-existing social realities. Even in a small country like Norway, the smart grid is not developed as one uniform concept. This diversity suggests that smart grids should be treated as situated technology rather than a catch-all silver bullet.

CenSES researchers have also looked into the industry and university collaboration in the technology FMEs[32]. Core findings are that, although trust was well established, the results have been less than optimal because of disparities in anticipated roles.[33] In order to reap the benefits from industry and university collaborations, firms must pursue active involvement by giving input to the research questions and enabling researcher access within their organizations. The thematic focus in the research centers may be inclined towards more fundamental issues that are relevant for several rather firm actors. The centers have also generated new bi-lateral projects where a firm may pursue a specific "problem-solving" trajectory with a selected set of R&D actors. Much of the consternation has been sourced to unclear expectations, dissonance, different goals and associated time horizons between industry and R&D partners. Development of the collaborative centers also triggered increased dialogue and reflections about relevance and division of labor among research actors. The research centers can thus also serve as important arenas for bringing together actors and increasing interaction which is important for nurturing technologies. The degree in which truly collaborative research practices actually manifest varies considerably from one industry to another in Norway.

Niche market formation

This is about shielding and protection. These are niches that shelter novelties from the mainstream market and competition with incumbent technologies. These niches can be geographic (familiar technology in new geographic context), technological (new technology offers advantage over old) or a combination of both. Firms may seek to move into specific segments (geographic and technological) and develop market niches based on the technological field and specific designs they engage in. At the same time markets can be created through various policy instruments such as regulations, public procurement, tariffs and subsidies.

Niche markets play several important roles in nurturing processes: they provide the opportunity for testing and verifying full-scale novel technologies in shielded market environments, and they are important for facilitating learning and interaction between different stakeholders (technology developers, users, regulators, consumers, scientists etc.) involved in new technology development. The experimentation of innovations is essential to processes of nurturing, given that this involves applying new knowledge. For an emerging field to develop, it is important that numerous such experiments and demonstrations take place to secure variety. This relates on the one hand to actor entry, but also to technological demonstration that can display the viability of new designs. Experimentation

[31] SKJØLSVOLD, T. M. & RYGHAUG, M. 2015. Embedding smart energy technology in built environments: A comparative study of four smart grid demonstration projects. *Indoor and Built Environment,* 24**,** 878-890
[32] FME: collaborative research centres on environmentally friendly technologies).
[33] LAUVÅS, T. & STEINMO, M. 2015. Development of immature technologies in long-term research centres: The role of proximity dimensions in converging institutional logics in university- industry collaboration. *DRUID15.* Rome; VIE, O. E., STENSLI, M. & LAUVÅS, T. A. 2014. Increasing Companies' Absorptive Capacity through Participation in Collaborative Research Centres. *Energy Procedia,* 58**,** 36-42

and demonstration is highly uncertain and linked to large risks both in technological and economic terms given that it involves the introduction of new technologies, business models etc.

The development of markets and user enrolment is a process intimately linked to nurturing technologies in terms of enabling user-producer interaction and critical learning processes based on couplings between use of technology and their further improvement. Important improvements in technology can arise from the disparity between what technologies initially provide and what users and consumers *de facto* require.

The literature is inconclusive on the importance of domestic markets for RE development. For example, only countries with sizeable domestic markets also managed to create industrial development within the wind turbine generator segment.[34] The importance of a domestic (or proximate) market varies not only across the life-cycle of different technologies and industries but also depends on the characteristics of the technologies.[35] In solar PV, which, with a dominant design in place, is a typical 'manufacturing industry', domestic markets seem to be of less importance during formative periods than the wind turbine industry, which is a complex product technology with a higher extent of product innovations occurring also beyond the era of ferment.

CenSES research on niche market formation

Of all the new RE technologies, offshore wind power is the most studied by CenSES researchers. The lack of a niche market for this technology in Norway has led to insufficient momentum for development of an offshore wind industry. The subsidy system does not provide sufficient support for this relatively immature technology. The tradable green certificate scheme (TGC) was introduced in Norway (jointly with Sweden) in 2012. Unlike schemes such as those found in Germany and the UK that differentiate level of support to different energy technologies depending on their level of development, the TGC scheme is technology neutral and thus favours RE technologies with higher maturity and associated lower costs. While the scheme may be economically efficient, it does not allow necessary support for niche market formation required by technologies that have not yet reaped sufficient learning and scale effects as well as supply chain development that allows for cost reductions.

The role of market formation policies such as feed-in tariffs (FITs) has also been studied in CenSES. Feed-in-tariffs are based on a learning curve rationale, where the reduction of tariffs is linked to a major innovation imperative, i.e. as tariffs decline, costs should also decline.[36] The declines in cost rely on the broader innovation dynamics in TISs, such as entry of firms, new knowledge development and resource mobilisation. This illustrates how demand side instruments may trigger other important processes that contribute to nurturing new technologies.

Several works produced by CenSES researchers have communicated the need for the creation of learning spaces in the form of pilot and demonstration sites to test and verify new products and service solutions within e.g. offshore wind power to propel the development of the industry forward.

---

[34] LEWIS, J. I. & WISER, R. H. 2007. Fostering a renewable energy technology industry: An international comparison of wind industry policy support mechanisms. *Energy Policy,* 35**,** 1844-1857

[35] HUENTELER, J., SCHMIDT, T. S., OSSENBRINK, J. & HOFFMANN, V. H. 2016. Technology life-cycles in the energy sector - Technological characteristics and the role of deployment for innovation. *Technological Forecasting and Social Change,* 104**,** 102-121.

[36] Hanson (2013)

The need for local nursing and testing markets is particularly articulated by smaller companies which do not have the resources and networks of larger (and often diversified) firms[37]. Smaller companies struggle more in accessing international markets, in part due to lack of ability to test and demonstrate new technologies.

Public procurement policies can stimulate the niche market formation of certain technologies. For example, some municipalities have enabled local market formation for heat production from biomass, which potentially serves to destabilize a 'heating regime' based on hydropower (electricity).[38] This suggests that in the Norwegian context, municipalities can play an important role as 'protectors' of energy technology niches. An open question however concerns the potential for upscaling these niches from specific local settings. This research shows that municipalities can carry out transition strategies in a very direct way, both as public procurers who establish markets and create demand, as well as through implementing new material infrastructures (e.g. charging stations for electric vehicles).

Several CenSES researchers have studied electrical vehicles (EVs) in Norway.[39] Fossil fuel-based cars are part of the existing energy regime. Because Norwegian power production is almost entirely renewable, opportunities for emission reductions are primarily found in transport and industry. It thus appears promising to stimulate niches that may challenge these regimes. In the case of EVs, policies have nurtured this niche by creating a 'protective space' through subsidies and positive regulations (that have provided EV users with benefits compared to fossil fuel-based vehicles, for instance free public parking). EV users have enjoyed both economic and practical benefits, such as the ability to use driving lanes for collective transport. In addition, the state has supported a positive and climate friendly understanding of the EV compared to other vehicles and transport technologies.

Mobilization of financial and human resources

As new entrants engage and experiment with emerging technologies, there is a need to mobilise human, financial and physical resources. The entry of new firms and research activities linked to an emerging field requires people and financing, and often also education and training to secure the variety and volume of competences to support industry, research and use.

A range of organisations and actors needs to become embedded and engaged in nurturing activities. This process relates to how actors discover opportunities and how shared visions and expectations, incentives, pressure mechanisms make actors engage with an emerging technology. In the early phases of industry creation, there is often a ‘technology battle’ and a situation with no ‘dominant design’.[40] This situation is characterized by a wide variety of premature technologies, with few industry standards or standardised solutions, which increases the difficulty of attracting investors as picking the winning technology is extremely difficult. Public sector involvement can influence this process through policy tools which enable inventors to test their designs (e.g. California wind rush of the 1980s) or providing incentives for investment.

---

[37] NORMANN, H. E. & HANSON, J. 2017. The role of domestic markets in international technological innovation systems. *Industry and Innovation*, 1-23

[38] RYGG, B. J. 2015. Paving the Way for Heat. Local Government Policies for Developing Bioenergy. *International Journal of Sustainable Energy Planning and Management,* 4, 57-70

[39] E.g. Ryghaug and Tøftaker, 2014

[40] ANDERSON, P. & TUSHMAN, M. L. 1990. Technological Discontinuities and Dominant Designs: A Cyclical Model of Technological Change. *Administrative Science Quarterly,* 35, 604-633

This process deals with entry into an emerging field and the manoeuvring of differing design options *within* a technological field. In emerging fields, variety is typically large, and sharing expectations on the direction of development can be important with regards to alignment of actors. This alignment matters both for learning processes and in terms of critical mass in attempts to affect the institutional framework under which the actors engage in activities.

In the earliest development phase, many emerging industries arise primarily through the entry of new, small independent firms.[41] A common pattern is that new firms with a broad set of technologies enter in the beginning, while larger firms enter at a later stage when the industry moves towards commercialisation.

New firms need to reach out across the emerging industry's borders in order to gain knowledge, complementary assets, partners, suppliers and potential customers to develop their businesses.[42] They will face major challenges due to emerging industries' limited standards, limited numbers of renowned players, high market and technology risks, and low external legitimacy due to limited track records.[43]

CenSES research on resource mobilization

As new firms do not have the ability to fund their development and growth entirely from internal or public sources, there is a large demand for external funding.[44] With investors who contribute with smart capital, i.e. who contribute not only with financial resources but also provide network access, technology expertise, and increased legitimacy, the companies can quickly move from pre-commercial to commercial stages. [45]All the aforementioned are especially important in the development of emerging industries to achieve higher technological maturity.

As value chains are non-existent in emerging industries, but rather fragmented across other industries, firms are dependent on established suppliers and market channels based in competing industries. For new firms, which often lack the contacts and partners that mature firms in mature industries have established over years of operation, this leads to an unstructured and anarchistic search for supply chain partners. Established firms may be difficult to engage as partners because they might be hard to convince of the potential of 'unproven' technologies in the earliest phases of the emerging industry.

For new ventures in emerging industries, an international mindset from inception could increase the possibility of accessing resources and overcome challenges associated with funding and technology development. This ability to venture internationally is especially vital in emerging energy industries where different policy regimes create different opportunities for funding and partnerships and can

---

[41] HOCKERTS, K. & WÜSTENHAGEN, R. 2010. Greening Goliaths versus emerging Davids — Theorizing about the role of incumbents and new entrants in sustainable entrepreneurship. *Journal of Business Venturing,* 25**,** 481-492; Løvdal and Aspelund, 2011

[42] SPENCER, J. W., MURTHA, T. P. & LENWAY, S. A. 2005. How governments matter to new industry creation. *Academy of Management Review,* 30**,** 321-337

[43] ALDRICH, H. E. & FIOL, C. M. 1994. Fools rush in? The institutional context of industry creation. *Academy of management review,* 19**,** 645-670; ZIMMERMAN, M. A. & ZEITZ, G. J. 2002. Beyond survival: Achieving new venture growth by building legitimacy. *Academy of Management Review,* 27**,** 414-431

[44] RASMUSSEN, E. & SØRHEIM, R. 2012. How governments seek to bridge the financing gap for university spin-offs: proof-of-concept, pre-seed, and seed funding. *Technology Analysis & Strategic Management,* 24**,** 663-678.

[45] BJØRGUM, Ø. & SØRHEIM, R. 2014. The funding of new technology firms in a pre-commercial industry – the role of smart capital. *Technology Analysis & Strategic Management,* 27**,** 249- 266.

help new firms access resources otherwise not possible to obtain.[46]

Firms enter emerging industries either as new entrants, R&D spin-offs or through diversification from other industries. Larger companies that have the capability to commercialize the technology further into the market often buy up young entrepreneurial firms that have been nurtured throughout their technological development process. At times these corporate buyouts of small firms benefit largely from early support from the entrepreneurial state. Larger companies may outsource their R&D efforts through corporate venturing activities[47] to avoid the losses associated with failed innovations and gain the buying power to pay for promising innovations.

Other CenSES researchers have looked more broadly into processes of resource transfer from established to emerging energy sectors in Norway.[48]

Legitimacy and social acceptance

The process of legitimation is related to creating social acceptance for new technologies in order to form markets, actors to enter, gaining access to resources and influencing or aligning with relevant institutions. New technologies are rarely well adapted to all potential user and application contexts and usually go through long periods of improvements and efficiency enhancements.[49] They are often subject to the "liability of newness". Therefore, a new technology and its associated actors need to be perceived as relevant, appropriate and desirable. The process of legitimation may be affected by a diverse set of actors, including proponents as well as adversaries of the new technology. The degree of legitimacy may in turn affect actor expectations, for instance in terms of managerial strategies.[50]

One dimension of this is how emerging technologies can be portrayed as problem solvers. In many national contexts, renewables contribute to emission reductions, enhanced energy security, and domestic job creation. Such overall policy goals help legitimise new energy technologies. Arguments to invest public money in RE technologies are usually grounded in the targets of energy policy, industrial policy, climate policy or a combination of these.[51] As a part of energy policy, RE is important to increase energy supply, to substitute depleting finite energy resources and/or reduce dependency on energy imports. As an industrial policy, RE represents an opportunity for 'green growth' industrial development, and job and value creation in rapidly growing global markets. Within climate policy, RE is key to reducing greenhouse gas (GHG) emissions. Underpinning the political will to pursue any of the aforementioned policies is the social acceptance to bear the costs upon society.

CenSES research on legitimacy and social acceptance

Research scientists are transition actors. For example, Åm[52] shows how scientists attempt to 'nurture' the solar energy niche on its risky path from lab to market by contributing to legitimising it as cost-efficient and with potential for value creation. A similar narrative is found in Heidenreich's

---

[46] BJØRGUM, Ø., MOEN, Ø. & MADSEN, T. K. 2013. New ventures in an emerging industry: access to and use of international resources. *International Journal of Entrepreneurship and Small Business,* 20**,** 233-253

[47] Bjørgum and Sørheim, 2014

[48] e.g. HANSEN, G. H. & STEEN, M. 2011a. Offshore vind - et norsk bedriftsperspektiv. Norsk Klimastiftelse og Senter for Fornybar Energi.

[49] Hanson, 2013

[50] Bergek et al., 2008, Hekkert et al., 2007

[51] European Commission, 2012; IPCC, 2012

[52] ÅM, H. 2015. The sun also rises in Norway: Solar scientists as transition actors. *Environmental Innovation and Societal Transitions,* 16**,** 142-153.

study of research scientists in Norwegian offshore wind FMEs.[53]

CenSES research has also studied how expectations in firms can affect legitimation, for example the. role of the petroleum industry in the development of the Norwegian offshore wind industry.[54] Many firms diversifying from the petroleum industry have however had wavering priorities and commitments in the new industry, which has contributed to misalignment in institutions such as impeding development of strong networks and “running in packs” strategies. In other cases, strong advocacy coalitions and the ability to run in packs was important in legitimacy creation and the ability to affect institutions, such as the development of new policies. The lack of ability to create a nursing or test market for offshore wind indicates that legitimacy is not strong enough to achieve such impact on policy-making and public involvement. The paper shows that the presence of many diversified firms with changing commitments may challenge institutional alignment, and thus affect the creation of legitimacy in the offshore wind industry negatively.[55]

Nurturing new energy technologies in Norway

The Norwegian energy system has developed around two strong “regimes”: hydropower and offshore oil and gas. Most RE technologies have a niche status. The systems surrounding these technologies are less mature than those of the regimes in terms of structures, institutions and practices. Hence, these niches are vulnerable and in need of support to facilitate their development and eventual deployment, both in national and international contexts.

The Norwegian solar energy industry emerged in part on the basis of key actors, knowledge bases and infrastructures in the existing energy-intensive ferrous metals industry.[56] The preconditions for use of new RETs[57] contributed to weak market formation for solar PV.
However, countries with RET deployment programmes fuelled by feed-in tariffs contributed to market formation. Emerging actors in Norway strategically targeted these emerging growth markets, such as Japan and Germany, and built up manufacturing capacity. Currently, the industry is struggling to compete with Chinese firms, but a range of firms and research organisations are still targeting local and international end use and raw-materials production. Knowledge bases established in the Norwegian offshore oil and gas sector have been foundational for the development of Norway's offshore wind industry.[58] Similar to solar PV, offshore wind has struggled with weak local market formation. Fluctuations in Norwegian activity levels have been strongly determined by varying public sector involvement and variations in political visions. These political visions have been influenced by external factors such as the development of an international market for offshore wind and varying activity levels in the offshore oil and gas sector. These two cases illustrate how dynamics linked to new RETs can occur in spite of weak local preconditions for use, given the international dimension of these emerging technologies.

---

[53] Heidenreich, 2014

[54] MÄKITIE, T., ANDERSEN, A. D., HANSON, J., NORMANN, H. E. & THUNE, T. M. 2016. Established sectors expediting clean technology industries? The Norwegian oil and gas sector's influence on offshore wind power. *TIK WORKING PAPERS on Innovation Studies.* Oslo: TIK

[55] Mäkitie et al., 2016

[56] Hanson, 2013

[57] RET: Renewable Energy Technologies

[58] NORMANN, H. & HANSON, J. 2015. Exploiting global renewable energy growth. Opportunities and challenges for internationalisation in the Norwegian offshore wind and solar energy industries. Oslo: Centre for sustainable energy studies (CenSES).

In most countries, reasons for nurturing RE technologies often involve energy policy arguments (e.g., security of supply), climate emission targets and industry development rationales. In Norway, the challenge regarding the market pull dimension of nurturing is that key drivers for public investment into the deployment of new RE technologies are not really at work. Electricity consumption per capita is about three times higher than the OECD average, and about eight times higher than the world average[59]. This consumption is almost entirely covered by clean and renewable hydropower.

The fundamental question is about the public rationales for nurturing new renewable energy technologies. Should new technological development be publicly financed to support existing regimes? To develop new export-oriented industries? To restructure and diversify the Norwegian oil economy? To meet climate targets?

The support for EVs is a unique example of active state policies to stimulate the introduction of a new technology that challenges the existing regime. From a value-creation perspective, an interesting aspect of this policy is that it primarily supports technological development in other countries producing EV vehicles. There is a clear analogy between Norwegian EV policy and the subsidised Californian wind energy market in the 1980s, where US support policies enabled the development of the Danish wind energy turbine industry. Another case in point is how generous feed-in tariffs for solar PV in various European countries have supported the development of Norway's solar energy industry. Not all value capture lies within the country providing the support, and innovations are often first taken to the markets willing to pay for them through various support measures.

The development of new RE technology in Norway is an explicit part of Norwegian energy policy. The Norwegian state utilises a wide variety of policy tools to nurture RE technologies along the (interactive) innovation process from basic research to commercialisation and diffusion in the market. Various instruments include research grants from the Research Council of Norway, technology and business development support from Innovation Norway, tax breaks from SkatteFUNN for sunk costs in innovation, and support for piloting and more market-ready trials by Enova. In a broader sense, support through SIVA for cluster programmes or INTPOW for international market access can be considered forms of nurturing.

However, whereas push policy instruments are plentiful in Norway, the lack of pull oriented mechanisms (market formation/support etc.) implies that the Norwegian policy mix for new RE technologies has shortcomings and lacks coherence.[60] Considering technological development and the nurturing of new technologies, the value of the tradable green certificate (TGC) scheme for supporting deployment of RE production capacity in Norway and Sweden can be questioned.[61] Although it is not entirely technology neutral, it does not distinguish between technologies in terms of subsidy levels. Many firms in offshore wind power and bio energy consider lacking framework

---

[59] World Bank, 2013

[60] NILSSON, M., ZAMPARUTTI, T., PETERSEN, J. E., NYKVIST, B., RUDBERG, P. & MCGUINN, J. 2012. Understanding Policy Coherence: Analytical Framework and Examples of Sector– Environment Policy Interactions in the EU. *Environmental Policy and Governance,* 22**,** 395- 423

[61] BERGEK, A. & JACOBSSON, S. 2011. Fremmer grønne sertifikater ny teknologi? *In:* HANSON, J., KASA, S. & WICKEN, O. (eds.) *Energirikdommens paradokser.* Oslo: Universitetsforlaget.

conditions and policy support key barriers to further development and deployment.[62]

Recommendations for policy makers

Nation states play a multi-faceted role: as regulators, as providers of capital for innovation, and in the commercialisation and diffusion phase as users of new technologies. Our recommendations for policy makers concern both *development* and *deployment* of new energy technologies. They are linked to the ambition of not only developing new RE technologies in Norway, but also providing the basis for new industrial development and value creation. Given the long-term prospects of global energy market developments, and the implications of expected declining demand for fossil resources on the Norwegian economy, we believe Norway has considerable potential for improving the nurturing conditions for new RE technologies. Limiting our recommendations primarily to RE production technologies, we have four specific suggestions. The first three concern development, whereas the last concerns deployment.

① Support early market formation

This could have at least three important benefits:

- it would give especially those actors with radical (new to the market/sector) solutions an opportunity to verify and demonstrate their technologies.
- it could support the build-up of new supply chain configurations, which would beparticularly valuable to the offshore renewable energy technologies.
- it would stimulate interactive learning among the different innovation system actors, and possibly stimulate commercialisation from Norway's R&D efforts in RETs.

However, there is good reason to differentiate in policy instruments according to the characteristics of RETs. In complex product technologies such as wind or tidal energy, where product innovation remains important even after a dominant design has emerged, a small demonstration market (e.g. linked to offshore O&G installations) could be highly beneficial for enhancing Norway's value creation potential in these industries. In RETs that are more of the 'manufacturing goods' type that to a larger extent benefit from economies of scale, such as solar PV, nurturing efforts should stimulate internationalisation and access to mass markets.

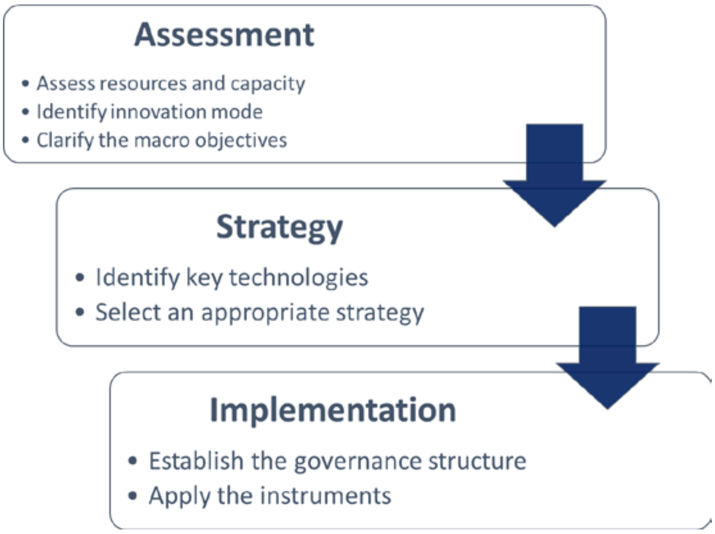
② One size doesn’t fit all - tailored solutions required

Policy makers need to tailor-fit their support, whether through frameworks, regulations, or subsidy mechanisms towards individual technologies based upon their needs, often reflected by their level of technological maturity and market readiness. t may be "misleading to lump together solar PV systems, wind turbines, biomass gasification, carbon capture and storage, and fuel cells when designing policy instruments to stimulate innovation in clean energy technologies."[63] The joint green certificate tradable mechanism has followed the one size fits all motto, much to the dismay of emerging technologies seeking to find their way into the marketplace. A practitioner’s guide for

[62] HANSEN, G. H. & STEEN, M. 2011a. Offshore vind - et norsk bedriftsperspektiv. Norsk Klimastiftelse og Senter for Fornybar Energi.

[63] HUENTELER, J., SCHMIDT, T. S., OSSENBRINK, J. & HOFFMANN, V. H. 2016. Technology life-cycles in the energy sector - Technological characteristics and the role of deployment for innovation. *Technological Forecasting and Social Change,* 104**,** 102-121.

effective renewable energy innovation policy is offered through IRENA[64], which provides the following roadmap:



We highly recommend policy makers to create tailor-made solutions based on available(natural) resources, the macro objectives government seeks to achieve (industrial value creation and job creation, emission reductions, etc.), and the state of technological and market readiness for the varying clean energy technologies it chooses to pursue to achieve more sustainable energy systems.

③ Support next-generation technologies

We recommend renewable energy in Norway to be approached more ambitiously, targeting technologies that are currently in very early stages of development. These include floating offshore wind, wave and tidal power, airborne wind energy, third generation biofuels and next-generation solar energy. This approach may not provide many kWh per NOK invested, nor many certain jobs in the foreseeable future. Neither will such an approach result in easily calculable reduction of climate gas emissions. However, it could be an important contribution to develop technology that enables countries (in the mid- to longer-term perspective) with less favourable natural conditions than Norway to extend their share of REs in their policy mixes. It could also provide the basis for future value creation in Norway based on technology exports (products and services).

④ Energy use policy

Regarding deployment, we see a need for a more explicit discussion on how to deal with the Norwegian energy (electricity) surplus. We call for a debate on an 'energy use policy'. The basic question is how to put electrons to work in a way that both benefits the global climate and domestic value creation., The latter is of increasing importance as the Norwegian economy must diversify from its current dependence on the petroleum industry. What are the prospects for new 'green' energy-intensive process industries in Norway? This idea of Norway as a 'green factory' challenges the current idea of Norway as a 'green battery' for Europe and suggests that Norwegian energy policy to a greater extent should be carved out in connection with innovation and industry policy ambitions.

[64] IRENA 2015

Key areas for further research

The Norwegian policy mix

No systematic studies have been conducted on the various support instruments and tools for technological development and innovation administered by key public agencies such as Innovation Norway, the Research Council and Enova. Current research is underway to address the success of university spin-offs in the renewable energy and clean tech sectors in Norway, as well as how startup firms that received support from Innovation Norway have evolved over time.
However, these ongoing efforts do not reflect the overall needs for a better understanding of the various policy tools that are relevant for the nurturing of new RE technologies in Norway. We know little about the effects of these instruments, their users, their success rates, their user barriers. Neither do we know to what extent different types of innovating firms (be they start-ups or established companies) make use of or benefit from different types of support instruments. Moreover, discussions with user partner Innovation Norway and the Research Council of Norway suggest that firms' involvement with various policy tools does not necessarily fit the rather 'step-wise' organization of support instruments from R&D (Research Council) via further (business) development (Innovation Norway) to commercialisation (Enova).

Understand technology development patterns

There is a need for better understanding of technology and industry development in Norway without a domestic market 'container' perspective. The key technologies (e.g. energy production technologies (wind, solar, bio etc.), energy system technologies (smart grid etc.) are developed in broader networks and systems of innovation and production, for instance within the scope of EU research funding schemes or the distributed innovation networks of large multinational companies. It would be useful to gain a better understanding also of how Norwegian R&D endeavours are part of broader innovation networks and contribute to technological maturation beyond the Norwegian industry and market context. A new EnergiX-funded research project RENEWGROWTH (2017-2020) – led by the TIK-center at the University of Oslo with other CenSES partners, will explore how Norwegian firms in the offshore wind and solar energy industries gain access to knowledge and other resources through transnational linkages on their paths towards internationalisation.

Export oriented renewable energy industry creation

Given the limited need for added electricity production capacity in Norway, coupled with the need to diversify the Norwegian economy, a key topic of further research is how new clean energy-related export-based industries can be fostered in the context of a small domestic market with limited demand for production capacity. These topics are now being pursued in two CenSES-related projects funded by the EnergiX-programme (InNOWIC (2016-2019) – led by the Department of Geography at NTNU alongside SINTEF. Whilst InNOWiC focuses exclusively on the offshore wind power industry, RENEWGROWTH has a broader empirical approach yet still focusing on upstream energy production technologies.

Downstream activities

Most research in CenSES RA4 has focused on energy production technologies. Technological developments leading to energy efficiency (e.g. in the energy-intensive process industries or the construction sector) have received limited attention, as has business model innovation in transport.

Energy efficiency

Through Enova and the TEK standards, the implementation of energy efficiency measures on the Norwegian building stock has had a clear effect, as evidenced by reductions in energy use per square meter. We still know little about the innovation and commercialization process within the field of energy efficiency for buildings. Clearly regulation matters here, as TEK standards have created a market for the newest products and solutions with measurable effects. For new buildings and renovation projects alike, one missing link in our understanding of innovation and commercialisation in the energy efficiency sector relates to the role of construction companies.

Smart grids & meters

A lot of focus is being given to social aspects of the smart grid and smart meters. Some work has been done to better understand the business model innovation opportunities in the smart grid.[65] However, many integrated power companies are scrambling to make sense of how to capture value as a result of smart metering, either through strategic partnerships with ICT firms, dynamic appliance control systems based on system prices, or bundled packages as ESCOs[66]. This research area is very fruitful with many unanswered questions and will most likely continue to have a strong demand for more multidisciplinary research in the future.

Clean transport: not just passenger vehicles

Transport is the single largest source for CO_2 emissions in Norway (road and air). Yet, within CenSES, little work has been conducted in the field of clean transport.

Whilst some empirical work on light duty freight goods transport was done[67], we still know little about how transport sectors are evolving with regards to new technologies. In the maritime transport sector, a new research project involving CenSES researchers from SINTEF and NTNU funded by the EnergiX programme) - GREENFLEET (2017-2020) – will assess the potential for sustainability transitions in the Norwegian shipping sector. It would be worthwhile to look further into the technological development and commercialisation of low- and zero-carbon energy technologies in other transport segments such as aviation and heavy-duty road transport.

---

[65] OTTESEN, S. Ø., TOMASGARD, A. & FLETEN, S.-E. 2016. Prosumer bidding and scheduling in electricity markets. *Energy,* 94**,** 828-843; ROOS, A., OTTESEN, S. Ø. & BOLKESJØ, T. F. 2014. Modeling Consumer Flexibility of an Aggregator Participating in the Wholesale Power Market and the Regulation Capacity Market. *Energy Procedia,* 58**,** 79-86.

[66] ESCO: European Skills/Competences, Qualifications and Occupations

[67] WALNUM, H. J. & SIMONSEN, M. 2015. Does driving behavior matter? An analysis of fuel consumption data from heavy-duty trucks. *Transportation Research Part D: Transport and Environment,* 36**,** 107-120.

Cen SES

CenSES — Centre for Sustainable Energy Studies
Faculty of Humanities
Norwegian University of Science and Technology (NTNU)
7491 Trondheim
Norway

www.censes.no
censes@ntnu.no

ISBN: 978-82-93198-33-8

Order a copy of the report: censes@ntnu.no