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Competitive policies in the Nordic Energy Research and Innovation Area eNERGIA

Synthesis report

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NIFU STEP

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Synthesis report

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Preface

This report outlines the energy research and innovation policy in the Nordic and Baltic countries – Denmark, Finland, Iceland, Norway, Sweden, Estonia, Latvia and Lithuania.

The report is the result of the research project Competitive policies in the Nordic Energy Research and Innovation Area (eNERGIA). The project was co-funded by Nordic Energy Research and NIFU STEP. The objective of the project was to determine possible policy interventions targeted at the development and commercial promotion of promising renewable energy production technologies in the Nordic countries.

The report is based on an analysis of the framework conditions for the sector innovation systems for energy production, with a focus on research and innovation policy in the Nordic and Baltic countries. We identified the key actors and institutions in all the eight countries studied. In addition, we conducted a performance assessment based on the quantitative indicators of publishing and patenting, international collaboration and funding data. Using these indicators as a basis, we conducted an analysis of the strengths, weaknesses, opportunities and threats (SWOT analysis) of the Nordic sector innovation systems for energy production. This analysis identified common or diverging characteristics, challenges, framework conditions, energy-technology specialisation and, most important of all, cases of good practice in key technologies.

The project included two workshops, and the results of these are also reported here. The outcomes of the workshops have been used in several parts of the project:

- A Nordic workshop on the environmental consequences of deployment at scale of these technologies to replace existing energy systems, with a focus on wind energy and photovoltaic energy, carbon dioxide capture and storage, and second-generation bioenergy.
- A Nordic workshop on policy implications for Nordic Energy Research.

The report comprises three parts:

Part 1: Country reports
Part 2: Technology reports
Part 3: Special reports

The results are summarised in the *Synthesis report.*

The authors of these reports are Antje Klitkou, Trond Einar Pedersen, Lisa Scordato and Åge Mariussen. We want to thank Nordic Energy Research for funding this project and our colleagues from NIFU STEP for their comments on the project. In addition, we would like to thank the participants at our workshops and the interview partners in our case studies for their valuable contributions.

Oslo, 1 July 2008

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Introduction

This eNERGIA project has studied the Nordic and Baltic countries' energy policy systems and energy sectors. The focus has been on how the different countries have succeeded in establishing conditions for successful development of renewable energy technologies. There has been a search for good practice in the different country's energy policy contexts. Good industrial practice has also been studied in selected renewable energy technologies. Energy statistics represent an important part of the documentation. A large amount of data and information has been collected.

This project has focused mainly on wind energy technology, solar photovoltaic technology, carbon capture and storage technology, and second generation biofuels technology. Hydroelectric energy is, of course, crucial in some of the countries and cannot be neglected, for example, as an important feature of Norway's path dependency. Our general conclusions and policy reflections may also be relevant to the policies for hydroelectric energy innovation. The project's focus on these four 'new' energy technologies has aimed at identifying common or diverging characteristics and challenges in the policy framework conditions and in the energy technology specialisations of the countries. Valuable information has also been gathered based on two workshops organised within the project. The first workshop has held on the topic of environmental consequences of deployment at scales of these technologies to replace existing energy systems; the second was related to policy implications. In addition to the workshops, the good practice cases of successful firms have contributed to critical views and issues in relation to challenges and opportunities in policy, technology, research and industrial innovation. The comprehensive documentation has shaped a basis for establishing the status of success in key renewable energy technologies of the countries.

This report summarises and presents the conclusions from the eNERGIA project. The other three reports document the results in much more detail. They include the statistics and other empirical material. The first report comprises a presentation of the countries that have been under scrutiny in the project – Denmark, Finland, Iceland, Norway, Sweden, Estonia, Latvia and Lithuania. The second report mainly deals with selected renewable energy technologies from different perspectives. The third report documents the SWOT analysis, the workshops and the case studies prepared in the project. There, we provide also a list of references that have been used for the reports.

Against this comprehensive and complex background of information in the energy domain, a number of observations at different levels have allowed us to draw conclusions and reflect on how Nordic policy-making can play a role. These conclusions are also presented in this synthesis report. We start with reflections regarding the different energy pathways of the Nordic countries. We then discuss the organisational framework of energy policy, and energy research and development. Political consensus and the alignment of energy policy, industry interests and civil society have turned out to be preconditions for the success of renewable energy strategies. Research policy in the energy field requires coordination, long-term stability and setting of priorities. We summarise the activities in the four technology fields in the Nordic countries and examine obstacles and possibilities for improved Nordic collaboration.

Energy in the Nordic and Baltic countries – policy institutions, strategies, R&D and innovation

The Nordic countries different energy pathways

The energy mix in the Nordic and Baltic countries reflects the different pathways of energy sector innovation and industrial development over the last 30 to 35 years. Energy policy has certainly played an important role. After the oil crisis in 1973 Nordic governments developed different strategies to address the crisis and to ensure the security of energy supplies. In this project we have studied the energy policy framework conditions and strategies in the Nordic countries. The different strategies revealed that the countries organised energy policy in different ways.

A possible strategy in the 1970s was to strengthen the more or less traditional energy sources available in these countries, like hydropower and oil and gas exploitation. This has been the dominant strategy for Norway. In Denmark and Sweden such a strategy was not an option, or at least it was not enough to handle the crisis. The natural conditions and the environmental concerns dominating the public debate moved the governments in Denmark and Sweden to go for other options.

The different paths of energy policy in the Nordic countries have resulted in the establishment of country-specific organisation of energy policy and energy R&D funding systems. Different technological domains have been prioritised and different types of support systems have been set up in terms of planning, concessions regulation and different types of subsidies. Energy R&D has become an important policy instrument for Nordic countries to meet ambitious national and EU energy policy objectives.

In many countries, the energy production structure is the result of more than 35 years of development. With the exception of Latvia, which has quite a lot of hydropower installed, the Baltic countries are highly dependant on nuclear and fossil energy. Iceland is a special case with its abundant hydroelectric and geothermal resources. In the other Nordic countries, the three or four decades after 1973 have been decisive in shaping the current energy structure. Together with Iceland, Norway perhaps is the most special case. In Norway, electricity generation is dominated by hydroelectric power which accounts for between 95 and 99 per cent of the total. About the same proportion of oil and gas production is exported. In Denmark, coal and natural gas are still extensively used for district heating and electricity production, despite of very good results regarding renewable energy sources. Denmark has also made strong efforts for improved energy efficiency, and strengthening of the electricity grid. Electricity production in Sweden is almost fossil-free, but nuclear power is still very important. Hydroelectric and nuclear energy are the two biggest energy sources in Sweden. In Finland, the diversity of energy sources is broader. The largest energy source for electricity generation is nuclear power, followed by different types of imported fossil energy, hydropower, and bioenergy.

In most Nordic countries there is a tradition of thinking energy policy as being closely associated to industrial and employment policy. In Finland, energy policy is intimately related to foreign policy as well. The winds of new public management have blown over the Nordic countries for a couple of decades, and have possibly weakened the emphasis on energy policy and the impact on employment and economic growth. In elucidation of the global policy attention towards sustainable development and the continuously developing ambitious policy targets aimed at solving the concerns over climate change, it is perhaps timely for the Nordic countries and Nordic policy to reinforce the emphasis on the positive economic and employment impact of investments in renewable energy systems.

Hence, innovation and industrial development have by no means taken similar pathways in the Nordic countries. On the contrary, the countries have different specialisation patterns. These patterns are strongly interwoven in the countries' industrial activities and structure. They are based on natural conditions and strongly interrelated with domestic consumer industries and domestic supplier and supporting chains. Illustrative examples include the Danish market pull of wind turbines from farmers and entrepreneurs, the Norwegian case of co-evolution of hydroelectric energy plants and energy-intensive process industries, and the current Swedish co-evolution of bio-fuels production and market demand by new bio-powered automobiles.

Energy technology value chains and markets are certainly not only domestic. The international and global dimension is highly present in the Nordic energy sectors. The global nature of the value chains in wind energy technology, in solar photovoltaic technology, and in hydropower turbines, is not only due to access to raw materials. Internationally leading companies such as Danish Vestas, Swiss/Swedish ABB, and Norwegian REC are maintaining their efficiency and competitive production in different parts of the world. Moreover, these companies are largely defining the market for researchers and skilled personnel on a global basis.

In this project we have studied successful renewable energy technology developments in the Nordic countries. In Denmark it is the wind and bioenergy specialisation; in Finland and in Sweden it is bioenergy and hydropower specialisation. In Norway, it is hydropower specialisation and the industrial adventure of solar photovoltaic technology. We have emphasised selected cases of good practice development – a global wind energy technology company in Denmark, a biomass cluster in Sweden, the mentioned solar photovoltaic technology case, and the special case of carbon capture technology development in Norway.

A number of questions have been important when analysing the good practice cases: What are the common industrial development characteristics of these cases that may be conditions for and explain success? What is successful set-up of energy policy framework conditions when the aim is to support renewable energy technologies? The energy policy systems include energy policy visions and strategies, organisation and priorities of publicly funded R&D, and other types of policy support mechanisms and instruments. How can we learn from the cases when we plan the reinforcement of existing or establishment of new pathways of renewable energy production?

Two recurring features seem to matter: the long-term horizon and dedication of central actors, and the systemic nature of the development processes. Long-term horizon and dedication of central actors imply the presence of a policy system, a R&D system and industrial actors who share views and beliefs about future options and scenarios. There is need for industrial actors with access to sufficient resources, the required knowledge and competence base, combined with visionary, entrepreneurial and professional managerial discretion. In sum, an important factor is the presence of large firms that can act on a long-term basis as locomotives making the main efforts. Our cases show that established firms with strong competence bases seem to be the right locomotive firms. These firms often have a global visibility: they have significant and intense research activities and they employ skilled workers from the international market.

The systemic nature of the development process is dependent on establishing early and close relations with key stakeholders. In our good practice cases there is strong documentation of early and maintained interaction. Interaction in the value chain is one evident and important feature. There is no locomotive without its customers and suppliers. Suppliers are often small and medium sized firms, supplying raw materials and components, more finished intermediates, research, maintenance and advanced technical services.

Less evident, but according to the findings in this project, highly significant, are the interrelations between the value chain and what we may call the policy and competence system. The policy system includes policy strategies, political authorities at different levels, and relevant government agencies. The competence system includes the education and research system.

The systemic features that we have observed are not only the concrete interactions that exist in projects of industrial development, between industrial actors and authorities giving concessions, the regulatory framework, policy instruments and incentives, planning and so on: it is the broader correspondence between the direction and objectives of energy policy and industrial actors' actions. We observe that an important precondition is a shared understanding between relevant actors that they are pulling in the same direction.

The existence of national incentive systems for renewable energy, giving investors expectations for a possible return on their investments, seems to be of vital importance for increased industrial activity. In our studies of the Nordic and Baltic countries we have come across several examples of how important good incentive systems are. The examples include large companies as well as entrepreneurs. The lack of a sufficient incentive system can, for instance, explain why the Norwegian company Statkraft is much bigger on new renewable energy abroad than in Norway. In the renewable energy sector companies' investments and activities abroad represent a good indicator of the quality of the domestic incentive system and framework conditions.

Organisation of energy policy and energy R&D

The integration of environmental concerns as part of energy policy is important if environmentally sound energy production is to be stimulated. In the case of Denmark and Sweden, environmental policies and energy policy have in some periods been under one ministry. Furthermore, specialised energy authorities have been established under the respective ministries in Sweden, Iceland and Denmark. The Swedish Energy Agency and the Danish Energy Agency also have the responsibility for managing energy R&D funds and supporting commercialisation in addition to other energy policy tasks. Compared to Norway and Finland, a stronger focus on commercialisation of renewable energy technologies is observed in the national energy R&D programmes in Denmark and Sweden. Finnish energy policy combines energy, economic and environmental policy. Public energy R&D is channelled through the generic funding bodies, TEKES and the Academy of Finland. In addition to being the main national research funding body, these organisations have an important policy advisory function. By contrast, energy issues in Norway are handled by the ministry responsible for oil and gas exploitation, but do not specifically support renewable energy R&D. The focus on commercialisation is strong in relation to R&D on oil and gas, and carbon capture and storage. All public research funds for renewable energy research are channelled through the more generic Research Council of Norway. For ensuring a sustainable pathway of energy policy, the influence of environmental policy and R&D funding for renewable energy technology could be strengthened in Norway.

The commitment of the Nordic energy ministries for renewable energy has also influenced the commitment of other ministries, especially the financial ministries, but also the ministries responsible for research and education and those responsible for trade and industry. The commitment of the energy ministries may be measured by the development of specific policy instruments to increase renewable energy production. Carbon taxes (Norway), feed-in tariffs (Denmark), investment grants (Denmark), and electricity certificates (Sweden), serve as examples. Another crucial measure is the support for research and development of new energy technologies.

The importance of political consensus

Alignment of energy policy, industry interests and civil society is regarded as a precondition for the success of renewable energy strategies. The different Nordic energy policy pathways were facilitated by strategic processes implemented by political parties, industry, R&D organisations and non-governmental organisations (NGOs). Energy strategies are discussed in parliament, and political agreements can be achieved across political parties ensuring a long-term commitment towards the chosen goals of development. These political processes are supported by intermediary organisations such as technology boards and industrial associations. The energy strategies have been conceived on political visions like, for instance, becoming completely independent of fossil fuels in the Danish and the Swedish case. The strategies are a way of translating the political visions into specified targets, priorities and policy instruments. A broad range of policy measures are developed, often in cooperation with industry players, including R&D policy measures that point to several actors – universities, research institutes and laboratories, and industry.

The political agreements on specified targets for reduced energy consumption and increased shares of renewable energy contribute to a higher commitment for fulfilling long-term visions in the energy fields of the Nordic countries. Action plans for fulfilling these targets are used for ensuring a continuous work on these issues.

Energy strategies have been developed at different policy levels. Besides the strategic agreements in the parliaments, governmental coordination has been important for ensuring success. Strategic planning has turned out to be a useful tool for realising government strategies, in the case for the Danish wind energy development. In addition to strategic processes in parliament, government and ministries, the contribution of NGOs and intermediary organisations to the debate on energy strategies is very valuable. In times of crisis these organisations can offer a channel to address public interests. They are open to environmental concerns and issues relevant for industry and civil society. A strong focus on the large potential of renewable energy technologies for addressing the challenges of climate change has contributed to an even stronger engagement of several of these organisations in the energy debate. Collaboration with research organisations supported this process.

Coordination of research

The Danish and Swedish energy authorities have long experience with their own R&D programmes targeted at renewable energy and energy efficiency. In addition, energy research is also funded by other public research funding agencies. Coordination of these research programmes and support measures is important for ensuring that funding will lead to the envisioned outcomes. Together with coordination, prioritising research topics, decisions on the level of funding, ensuring the quality in the selection of projects and supporting systematically capacity building, are also addressed here. The use of monitoring processes and evaluation tools for measuring the quality of the funded projects is important. A crucial issue regarding research funding is stability over time; sudden cuts in government allocations as experienced in Denmark in 2002 and 2003, and in Sweden in 2005, are detrimental to the research community. Energy research funding has to cover a broad range of research activities and not just one segment – basic research, applied research, development and demonstration activities need attention. When drastically diminishing funding for basic research, as was the case in Sweden in 2005, collaboration in international projects can also be endangered. Commercialisation of research results is important, but should not be the sole focus.

Nordic technology activities and priorities

As there is no single technology area that will solve the challenges for a cleaner and more competitive future, national energy R&D strategies normally include a portfolio of technologies. Determining R&D energy priorities is a process to help governments optimise national investment in R&D. Even if the main vision for the long term energy scenarios are well defined in most Nordic countries, the technology priorities for renewable energy and the allocated resources differ between them to some extent. Priority is given to renewable energy technologies that suit the Nordic countries' particular characteristics, such as bioenergy in Finland and Sweden. In Denmark wind power is (still) a priority and second generation bioenergy technologies receive increasing attention from policy makers. In Norway, the emphasis is mainly on carbon capture and storage, at least in terms of research funding. The current policy strategy prioritises also other renewable energy technologies, but the funding has not yet increased considerably.

In this project we focus on four particular technology areas: wind energy, second generation biofuels, photovoltaics, and carbon capture and storage.

All Nordic countries, excluding Iceland, have *wind energy* installed, but to very different degrees. Energy from wind is increasingly considered to be important for reducing green house gases. If the natural conditions for wind capacity are taken into account there is large potential for further installation of wind power in the Nordic region. New efforts to increase wind power are taking place in the Nordic countries, nevertheless at a different intensity level. With StatoilHydro in the lead, the world's first full scale offshore floating wind turbines are being planned off the Norwegian coast. Norwegian technology strongholds in wind energy are related to the oil and gas industry which is relevant for specifically developing offshore wind power.

Considerable efforts are being made with regard to RD&D in second-generation biofuels. Testing plants for *second-generation biofuels* based on cellulose ethanol are being established in Sweden. The presence of leading ethanol suppliers represents a promising starting point for developing and improving second-generation biofuels technologies. While the Swedish authorities are heavily supporting the introduction of first generation biofuels, the authorities in Denmark are showing more scepticism towards first generation ethanol and instead are choosing to invest in and give exclusive priority to second-generation technologies. This is, however, a technology that has not yet reached the commercial stage. It is also yet unclear how it will be possible to fund the up-scaling of existing demonstration plants.

In the field of *photovoltaic or solar cell* research, different technological pathways are being observed. In Norway, there are industries with world-leading expertise in photovoltaic energy technologies in silicon-based solar cells. However, photovoltaic energy technologies have not been the core attention of the Norwegian authorities in terms of public funding and R&D programmes. The research activities in Sweden are mostly specialised in second-generation photovoltaics, i.e. thin film solar cells. The solar cell industry Sweden has grown rapidly the last years, mainly in the manufacture of modules from imported solar cells. Denmark is choosing a different path than Norway and Sweden, as primary focus is on so called third-generation solar cells, a technology that has not yet reached a commercial stage. A Nordic Centre of Excellence is coordinated by the Institute for Energy Technology and funded by Nordic Energy Research. Here, attempts are made to mobilise the strong photovoltaic research on new generations of photovoltaics in the other Nordic countries.

Carbon capture and storage (CCS) has been addressed differently by the Nordic countries. The Norwegian authorities have implemented several policy instruments and measures for strengthening the focus on CCS. Funding of RD&D on CCS has high priority in Norway. Norway has the highest share of funding on CCS in relation to Gross Domestic Product (GDP) compared to other countries. Important industry actors are StatoilHydro with long experience in CO_2 storage and several ongoing projects, and Aker Clean Carbon, a technology developer for CO_2 capturing. For various reasons, CCS-related R&D is of minor importance in both Finland and in Sweden. There are however, Swedish energy companies, such as Vattenfall, which are investing in CCS technologies in Sweden and abroad. Despite the use of coal in combined heat and power plants and oil and gas production in Denmark, policy makers do not (yet) give high attention to develop CCS technologies, something which is also manifested in low funding and government support for R&D in this field. However, the new Energy technology development and demonstration programme has CCS as one of many priorities. Danish energy companies, as DONG Energy, Elsam and Energi E2 are engaged in CCS projects.

Patenting and publishing as indicators of the strengths in the Nordic science base

The Nordic countries performance in patenting and publishing in the four technology fields largely reflects our previous findings. The comparative patent analysis reveals that Denmark has a very high activity level in two of the selected technology fields – both wind and second generation biofuels – and also in hydrogen. Finland and Sweden have a high level of activity in second-generation biofuels, but in the other fields they are not very active. Norway has a high activity level in several fields – photovoltaics, CCS, hydropower and hydrogen: only in wind and second-generation biofuels there is a low activity level.

Nordic and Baltic R&D collaboration

Research funding agencies support collaboration with partners in the European framework programmes, but the own programmes are still restricted to the national actors. Even the openness of the national research and development programmes to Nordic partners is still not sufficient, and we assess the lack in openness as a major obstacle to improved Nordic research collaboration. Nordic level cooperation is steered under the Nordic Energy Research (NER). NER is a limited but very dedicated policy instrument under the Nordic Council of Ministers for supporting energy research and development in the Nordic and Baltic region and North-west Russia. NER is funded by the Nordic Council of Ministers and by the Nordic countries. The fields of support show a clear focus on new renewable energy technologies. Interesting also is the high share of policy projects that address political and economic needs for changing the existing energy systems. Nordic Energy Research has contributed to improved collaboration between the Nordic and Baltic R&D organisations and has triggered considerable co-funding from other sources. The projects include not just public R&D institutions but also R&D-intensive firms. The research and development funding by Nordic Energy Research is a valuable policy instrument of the Nordic Council of Ministers for improved research collaboration on renewable energy issues, but the funding level is limited. The national funding means are much higher, and an opening of these national programmes for the other Nordic countries could push the Nordic research forward. Funding and human resources in the individual countries are limited, and bundling up these resources could enable the Nordic countries to become forerunners in selected technology areas, even at the global scale. For this aim political commitment is required.

The Nordic countries' R&D collaboration in renewable energy takes place at different levels. Nordic energy researchers are well represented in international research networks and EU research framework programmes. The international Energy Agency is also an important international arena for research interaction in the research fields that we have investigated.

Collaboration under the EU framework programmes has been an important driver for Nordic energy research. This is especially the case for Denmark and Sweden, and to some extent also for Norway. The involvement of the Baltic countries is still minor, but could be improved by including these countries in existing Nordic collaboration networks. Hitherto, the Baltic countries have been involved in larger network projects only to a minor degree compared to the Nordic countries. The collaboration of

Norwegian R&D institutions with Baltic institutions is still rather limited, while the strong involvement of industry actors in the Norwegian projects is remarkable.

The Nordic countries, and to some degree also the Baltic countries, are well represented in the ERA-NETs related to renewable energy technologies – ERA-NETs for bioenergy, hydrogen and fuel cells, photovoltaic energy, innovative energy research and clean fossil energy technologies.

Environmental impact

This project's workshop on environmental impact of renewable energy technologies focused on photovoltaic technologies, wind energy technology, second-generation bio-energy and carbon capture and storage. The workshop gathered researchers and experts with competence in environmental assessment of the different technological areas. In the presentations and discussions, a range of issues of environmental impact emerged.

The main message was that there is need for more and systematic research and work on the environmental impact of these technologies. More research is above all needed in order to develop the technologies with as low environmental impact as possible, but more research is also needed to improve the knowledge-base for policy-makers that are to decide on investment and allocation of funding. A technology-specific example is the lack of research on carbon storage. There is a major need for creating long term monitoring systems of geological storage sites and international regulations for CO_2 storage. There is need for updated data that can be fed into the Life Cycle Inventory – the first step of Life Cycle Analysis. There is, in fact, urgent need for improvement of the data quality, enabling improved Life Cycle Analysis in different technological domains.

Environmental impact assessment is applied in relation to specific investment projects. The strategic planning approach, used with success in two of Denmark's latest offshore wind projects, is basically the consensus-establishing process based on interaction between public opinion, policy actors and industrial actors. A prerequisite for a successful strategic planning process is the presence of a thorough environmental impact assessment as knowledge-base.

An overall issue is related to the basic problems of path dependency of dominant energy systems and the corresponding dynamics in renewable energy policy governance. Is this a question of *greening of energy policies*, is it a question of *integrating energy into environmental policies*, or is it an issue of strengthening the *interaction of environmental and energy policies*? If the political objective of sustainable development and promotion of renewable energy is to be reached, there is need for an increased degree of policy coordination across issues (and ministries) dominated by strong sector interests.

Natural conditions

The presence of favourable topographic and geological characteristics combined with natural resources and climatic features are all conditions determining availability of primary energy. Some are directly or indirectly usable in the form of, for example, hydro, wind, wave or geothermal power.

Northern Europe has excellent preconditions for exploiting and developing its natural resources for power production. Due to their topography, the Nordic countries, with the exception of Denmark have abundant hydropower. Both Norway and Sweden have one of the highest hydro potentials in Western Europe. Norway has today over 99 percent of its electricity supply derived from the abundant hydropower. Together with nuclear energy, hydropower is also the largest energy source in Sweden and Finland. In Iceland, hydro together with geothermal power are the most important sources of primary energy, of which a large part still remains unexploited.

In both the Nordic and Baltic countries, forests cover a large part of the total land area. There is a naturally large selection of biomass to produce bioenergy from. Large parts of the forest biomass resource remain unutilized. In Denmark, the bio-energy resources used are largely based on wood, waste and residual products from agriculture such as straw, and biomass for biogas production.

While renewable sources of energy are abundant in most of the Nordic and Baltic countries, fossil fuels also play an important role. The presence of oil and gas under the Norwegian continental shelf has become an important element in the Norwegian economy. Extracted oil and gas in Norway is not used in domestic energy consumption, while energy consumption in Estonia relies mostly on domestic oil shale. The well-explored continental shelf may be used for geological storage of CO_2.

Some of the strongest winds are observed in the Nordic countries and are particularly strong along the entire coastline and large parts of the inland of Norway. The Swedish South-western coastline has particularly good wind conditions. Finland also has excellent wind sources. These excellent wind conditions have so far been exploited mostly in Denmark.

Utilisation of wave power is also being explored. Particularly strong waves are observed along the Norwegian coast and outside the west coast of Sweden. In both countries the potential of developing wave power is being tested.

Denmark

The Danish success story in *wind power* technology is due to a clear long-term policy focus. The wind energy industry has enjoyed a forceful policy support and good institutional frameworks. The Danish energy authority has developed a broad range of activities to reduce the required energy. A main effort was a focus on energy efficiency and saving. Agreements on energy saving with industry, energy standards for buildings and electrical equipment and taxes on energy consumption have been introduced. Coal had to be used more effectively by spreading combined heat and power production for district heating purposes. As a consequence, the level of energy consumption in Denmark has been more or less stable over the last thirty years.

The use of renewable energy resources was the complementary strategy. On the one hand, wind turbine capacity was built up for producing electricity. Development of bio-energy, mainly by use of wood, waste and straw, has increased the share of the overall energy consumption covered by renewable sources – from three per cent in 1980 to seventeen per cent in 2007. Renewable energy has improved Denmark’s energy supply security and is central for fulfilling the government's long-term vision of making the country independent of fossil fuels.

The Danish Energy Authority has introduced support mechanisms for renewable energy technologies like investment grants, feed-in tariffs and market-based tenders. An important issue is not to over-subsidise mature technologies. In this context we assess that subsidies should be reduced gradually, but this has to be clear from the start. A critical lesson for the deployment of renewable energy technologies is the need for transparency and confidence-building measures for attracting investors. The long experiences with R&D programmes under the energy authority, including also the public service obligation programmes managed by Danish energy industry, have been a valuable contribution to Danish energy research and have been supplemented by research funding under the Strategic Research Council and the Danish National Advanced Technology Foundation.

Feed-in tariffs have contributed to the success in wind energy production. Feed-in tariffs and other institutional frameworks enabling a growth in production are likely to stimulate the industrial capacity and increased attention by corporate actors. The strategic planning process has proved to be a successful tool compared to the one-by-one approach. A suitable legislative and planning framework has been important to support local initiatives. Intellectual property rights are increasingly crucial for industrial actors that collaborate in research and development together with research institutes and universities. The Danish case study revealed that there is need for revision of the regime for protecting intellectual property rights, which in many countries favours the research institute and university side.

The Danish energy industry covers the whole value chain of energy-related industry from raw material extraction in the North Sea, use of waste or bio-materials, to energy production in combined heat and power, wind turbines, energy transmission/ distribution and consumption of energy. Export of energy technology, and especially wind energy technology, is considerable in Denmark. The Danish wind turbine industry served 30% of the world market in 2007. An overview of the most research-intensive energy companies in Denmark indicates that some of the largest companies are active in several energy technology fields, while most of the companies are specialised in one field. Wind and bio-energy are the biggest domains. The strengths in the Danish energy sector include high energy efficiency, wind power, district heating and waste management. In terms of opportunities the new large-scale investment program from DONG Energy is promising. Developments in the areas of fuel cells, energy efficiency and bioethanol, and the prospects for export from the wind industry are promising.

Sweden

In Sweden, public pressure for phasing out nuclear energy production in the 1980s became a strong driving force behind research on renewable energy. The vision in Swedish energy policy is that the country will obtain all its energy from renewable energy sources in the long term. There are several reasons for the Swedish authorities to prioritise the development of bioenergy technologies. The presence of large biomass resources, the forest industry and vehicle manufacturers are of key importance. The introduction of various policy instruments has contributed to a gradual increase in the usage of renewable resources. The two most important instruments were carbon dioxide taxation and the electricity certificate system introduced in 2003. The latter has the aim of increasing the share of renewable electricity.

Since 2005, the Swedish Energy Agency, a government agency under the Ministry of Enterprise, Energy and Communications, has the main responsibility for allocating funds for energy research. Within the research community concerns about the unpredictability and instability of the state-funded energy research have been expressed in recent years because research allocations for energy research were reduced by almost a half from 2004 to 2005. Former earmarked funds for basic energy research administered by the Swedish Research Council were eliminated. However, after pressure from the research community the government allocation for energy research increased again during the last two years.

The data for Swedish research-intensive energy firms shows that many companies are active in more than one technology field, such as ABB and Vattenfall. Strong features in the Swedish energy industry are in bio-energy, photovoltaic technologies, hydropower and wind energy. The ethanol company, SEKAB, has a great potential for being an important world producer of second generation bio-ethanol in the coming five to eight years. Sweden is also the leading Nordic country in using public incentive mechanisms (tax incentives and subsidies) to foster the development and implementation of a functioning biofuel market. The main challenges in reaching full-scale commercial plants for cellulose-based ethanol imply high risk and high costs. Estimations indicate that a single ethanol plant would require up to one billion SEK to up-scale the ethanol production to a commercial size. There are also many uncertainties connected to the success and economic returns of the first commercially viable plants.

Finland

In Finland, the general concern about security of supply has continued throughout the last fifty years due to the country’s delicate geo-political situation. Energy policy in Finland is often seen as security or foreign policy. Finland has balanced carefully the situation of influence from Soviet/Russia in the East and Sweden in the West by maintaining energy business relations on both sides. Exploitation of renewable energy, in hydropower and bio-energy, represents two of the four-legged foundation that Finland has in energy supply. Own nuclear energy and imported fossil fuels are the two other legs. After the fall of Soviet Russia, the Finns have thoroughly established research and development activities in the areas of energy important in the country, particularly in bio-energy. Currently, the National Energy and Climate Strategy from 2005 is making impact and the emphasis on environmental concern and renewable energy sources is being reinforced. There are tax subsidies, investment subsidies and guaranteed access to the grid for renewable energy based electricity. The new, large Ministry of Employment and the Economy, which is the merger of several ministries, has the responsibility for energy sector research through the Finnish Funding Agency for Technology and Innovation (TEKES). Other key funding institutions include the Academy of Finland, which administers basic research, and the Finnish Innovation Fund. The largest areas of research are energy end-use and bio-energy. Five large-scale energy-related technology programmes are currently active (2003-2013). Research and industrial development in energy technology is to be particularly concentrated to the five so-called Centres of Competence around the country.

When it comes to industrial agglomeration, the renewable energy sector is historically intimately related to the pulp and paper cluster, which explains why bio-energy in particular wood and wood-based fuels are so important. There is significant wind energy activity under planning in Finland. Finland has chosen to further invest in nuclear power which might slow down or divert attention away from renewable energy technologies. This trend is further confirmed by the four new nuclear power concessions being considered. At the same time, however, the current research and technology policy initiatives, which include the Centres of Expertise Programs and The Energy Technology Cluster Programme, allocate significant resources to renewable energy research and technology development. These initiatives are credible and ambitious. These efforts might result in increased renewable industrial activity. They therefore represent a counterbalance to the current revitalisation of nuclear power investments in the country.

Norway

In Norway the introduction of the carbon dioxide emission taxes for petroleum related activities on the continental shelf, in force since 1991 was a driver for oil and gas companies to engage in carbon capture and storage R&D. The Norwegian Ministry for petroleum and energy has funded mainly research, development and demonstration programmes for an enhanced exploitation of oil and gas resources. The Norwegian Commission on Low Greenhouse Gas Emissions was appointed by the government in 2005. The Commission concluded that carbon capture and storage is one of many measures for reducing greenhouse gas emissions and emphasised also the need for higher energy efficiency and increased use of renewable energy sources. Energy consumption in Norway is at a very high level: oil and gas exploitation uses a large share of the electricity, and in addition there is energy-demanding process industry located in the country. This industry traditionally received very favourable energy prices and industry policy is now under pressure for finding new solutions. Carbon capture and storage for gas power plants is seen as one possible element, but policy measures for increased introduction of renewable energy are still neglected in Norway.

A main challenge in Norway is to combine the role of significant oil and gas supplier with the ambition to be leading nation in environmental and climate policy. This challenge has resulted in the Norwegian government investing heavily in *carbon capture and storage* technologies together with Norwegian oil and gas companies and the largest mechanical/chemical engineering companies in the country. In recent years, the Ministry of Petroleum and Energy has established a centre of expertise on carbon capture and storage and is co-funding the research programme for this topic with the Research Council of Norway. Funding renewable energy research and development is mainly the responsibility of the Research Council of Norway. A recent initiative supported by the ministry has contributed to the development of a research strategy for renewable energy based on a process with broad participation from industry, research organisations, intermediary and non-governmental organisations. It is up to the ministry what will happen with the proposed strategy. Setting policy priorities for specific technologies has been shown to be a difficult process.

In Norway, the dominance of the oil and gas sector, which is mainly an export industry, and hydroelectric power – mainly for domestic use, represents the bulk of energy sector industrial activity. We have emphasised the Norwegian photovoltaic technology industrial venture and the Norwegian carbon capture and storage activity, as good practice cases. While the carbon capture and storage activity has involved huge amounts of research, the photovoltaic industrial development has not involved much research hitherto. There are several important Norwegian industrial actors in carbon capture and storage development. The industry actors have a high level of research and development activities and they collaborate with the most active Norwegian research and development organisations in this field.

Iceland

In Iceland, more than 99% of electricity production and over 70% of total energy production stems from hydropower and geothermal energy sources. The successful exploitation of the geothermal energy and hydropower has contributed to attract foreign investment into the country, mainly in power-intensive industries and is one of the main driving forces behind Iceland's economic growth in the last years. The National Strategy for Sustainable Development was drawn up by the Icelandic Government in 2002 and was developed through consultation between ministries, stakeholders and civil society. The purpose of the strategy was to set up priorities, set long-term goals and to define and set up criteria to measure progress. One important objective in the government's Climate Change Strategy 2007–2050 is to further reduce the use of fossil fuels in favour of renewable energy sources and climate-friendly fuels. The government is funding R&D on carbon sequestration and production of synthetic fuels from hydrogen. In Iceland, the National Energy Authority is the administrative and regulatory agency on energy issues, also supports research related mainly to hydropower and geothermal energy. The authority also serves as a governmental adviser on energy issues.

In 2006, Reykjavík Energy and all universities established an autonomous Environmental and Energy Research Fund which is intended to become a venue for collaboration in energy and environmental research.

Landsvirkjun is the national electricity company. Its purpose is to produce and provide electricity to heavy industry and to sell electricity to smaller providers, such as Reykjavik Energy and Iceland State Electricity. Landsvirkjun has eleven power plants, mainly hydropower and steam power plants. Currently, the largest hydropower plant, the Kárahnjúkar Hydropower Project is being built by Landsvirkjun. The completed plant will provide power to an aluminium smelter industry. The plant has been heavily criticized for its environmental and economic impact in the region. There are five main district heating companies in Iceland, the largest one being the geothermal plant Orkuveita Reykjavikur.

The Baltic countries

The Baltic countries have still to overcome the consequences of the Soviet era. All three countries have undergone extensive reform efforts and have growing economies. To ensure a reliable energy supply can be seen as one of the major targets. Renewable energy sources are still not the main focus. Acknowledging the common challenges that the three states are facing, such as rapid economic growth, increase in oil and gas prices, dependency on gas supply from one supplier and the challenges regarding nuclear power, the Baltic States adopted a new common Baltic Energy Strategy in 2007. In order to meet the requirements and provisions in the European Union the Baltic countries set up strategic objectives which include the integration of the power and gas supply systems into the European energy system and energy markets, a diversification of primary energy sources and supplies, and an increase of the contribution of renewable and local resources, an increase of the energy efficiency and the strengthening of energy research and development. Regarding education and research and development for supporting the energy sector, the Baltic countries may have a problem because they are not able to establish a critical mass in different domains. Collaboration between these countries, but also with Nordic, European and other global players is therefore a major issue.

The energy sectors in the Baltic countries are still dominated by the incumbents from the state-owned energy monopolies: Eesti Energia in Estonia, the Ignalina Nuclear Power Plant in Lithuania, and Latvian Gas and Latvenergo in Latvia. There are still relatively few small and medium sized companies in the energy sector in these countries.

Conclusions and policy recommendations

In this section we present a list of conclusions and policy reflections based on the findings from the eNERGIA project. In some of our conclusions and where relevant, we have included suggestions for potential Nordic policy action in the field of renewable energy.

Policy framework conditions and energy policy

Renewable energy policy visions show the way

The findings in the eNERGIA project indicate that energy strategies built on ambitious political visions based on sustainability criteria have a positive impact on directing the efforts towards desired goals. The Nordic Council of Ministers could have an important role in including and supporting common visions and setting of common Nordic goals and Nordic energy research policy could take the role as facilitator for this process.

Long- term horizon and commitment for sustainable development

The Nordic countries show strengths and competitiveness in different renewable technologies and technologies for cleaning energy production based on fossil fuels. The studied policy, research and innovation systems seem to have at least two overall recurring crucial features: on the one hand, the long-term horizon and the commitment of stakeholders for sustainable development; on the other, the systemic nature of the development processes. The systemic features that we have observed are not only the concrete interactions that exist in projects of industrial development between industrial actors and authorities responsible for concessions, the regulatory framework, policy instruments, planning, and so forth, – it is the broader correspondence between the direction and objectives of energy policy and industrial actors' actions. Long-term horizon and dedication of central actors have to do with the importance of having a policy system, an R&D system and industrial actors which share views and beliefs about broad objectives of renewable energy innovation. There should be room for many technologies in the future. Stakeholders in Nordic policy and research should develop activities with these central factors in mind.

The role of specialised energy authorities

The operation and implementation of an energy policy oriented towards renewable energy production seems to have better conditions where a specialised energy authority has the overall responsibility. This also applies to the structure of energy research funding. It seems that such sustainable energy policy and research have better conditions in the Danish and Swedish contexts where one ministry is the policy-maker and one energy authority is the main research funder. The development of new renewable energy in Norway does not seem to have the best preconditions under the Ministry of Petroleum and Energy. The path dependency and commercial interests in relation to fossil fuels and hydropower seem to supersede new renewable energy. The same Norwegian policy system can, however, refer to the good results for carbon capture and storage technology.

Policy governance and coordination

In the Norwegian context especially, the discussion on the importance of highly committed energy authorities is strongly linked to the degree of integration of energy policy with environmental policy. There is a need for emphasis on environmental policy issues in energy policy in order to ensure a sustainable energy pathway. In other words, there is a need for more policy coordination. It can be a question of *greening* energy policies, or of integrating energy into environmental policies, or to strengthen the interaction of environmental and energy policies. No less important is the presence of a more visionary and determinate top level government, which may also be a precondition for improved policy coordination.

Unity is strength: alignment of policy, research, industry and civil society

Renewable energy policy visions need to be underpinned by a broad consensus about the strategies. Sharp disagreements can slow down or hinder development and investments. Alignment of energy policy, industry interests and civil society is assessed to be a precondition for the success of renewable energy strategies. The different Nordic energy policy pathways were facilitated by strategic processes including political parties, industry, R&D organisations and non-governmental organisations. Energy strategies are discussed in parliaments and political agreements can be achieved across political parties ensuring a long-term commitment towards the chosen goals of development.

Strategic planning approach

The strategic planning process has proved to be a successful tool compared to the one-by-one approach. The latter involves only the investor and the relevant authority. The strategic planning approach, as it has been used in offshore wind investments in Denmark for example, implies interaction between governmental/regional authorities and all stakeholders about the impact of the planned investments. It includes strategic screening of grid connections, assessment of issues such as wind resources, and the whole range of environmental impacts that may be relevant.

Knowledge, strategic planning and communication/ interaction

More knowledge, research and strategic planning represent ways of preparing for consensus and aligning different actors' understanding and opinions in relation to new renewable energy technology investments.

Challenges and opportunities with the rapid market growth for renewables

Both a challenge and an opportunity for the Nordic countries are represented by a rapidly growing global competitiveness and a rapid market growth in renewable energy technologies. In this context a strong science base combined with high industrial productivity, backed by strong political commitment, are crucial factors for becoming a successful global player. The results of our analysis indicate that the Nordic countries, within different fields of specialisation, have great potential of becoming such players in the renewable energy technologies covered by this study.

Denmark has, above all, success in wind power technologies. The industrial activity and the science base are strong.

In photovoltaic energy technologies Norway has a clear technological and industrial advantage compared to the other three Nordic countries. There is urgent need to strengthen the science base in Norway in order to prepare for the perceived rapid technological developments in this domain globally.

Sweden has significant industrial and research activities in many renewable energy technologies, particularly in bio-fuels. Sweden has great potential of becoming an important producer of second-generation bio-fuels. However, timing and availability of funding for up-scaling demonstration project are major challenges.

The strategies and plans for renewable energy research and technological development in Finland are impressive. Bioenergy is the main focus. But Finland has chosen to renew its investments in nuclear power. It remains to be seen, but the risk is that the resources allocated to build up nuclear power slow down or divert attention away from renewable energy technologies.

Energy policy instruments

Legislation, planning and incentive mechanisms

A suitable legislative framework, the above-mentioned strategic planning approach and good support mechanisms have been important to support (local) initiatives of renewable energy innovation. A considerable problem in Norway is the lack of support mechanisms such as feed-in tariffs or electricity certificate systems. Renewable energy investments are simply not considered viable by investors. There is a specific need in Norway for incentive mechanisms that will foster the development, especially wind power and bioenergy.

Important incentive mechanisms

Feed-in tariffs have contributed to the success in wind energy in Denmark. The Swedish electricity certificate system, although criticised for being expensive has contributed to a significant increase in renewable energy. Investment subsidies directed to certain types of renewable energy plants are also considered a successful policy instrument. The litmus test of whether a system is working or not should be based mainly on information on how investors assess and expect returns on investments.

Importance of not over-subsidising mature renewable energy technologies

In order to foster the best possible technological solutions, for example the latest wind power technology, it may be a problem that incentive mechanisms include investments in mature/old renewable energy technologies. The incentive mechanisms need to be adjusted accordingly to technological maturity.

Stable long-term funding and coordination of R&D

Renewable energy technology development is a long-term activity that requires stable long-term RD&D funding. New energy system building implies the acknowledgement of the need for a broad range of RD&D efforts and commercialisation. The Nordic region can make a difference, if in particular RD&D efforts are coordinated.

Costs of demonstration plants and scaling-up, need for funding and venture capital

Many of the cases of technological development that are studied in this project have the high costs of demonstration and scaling-up as main challenge. This applies in particular to CCS and bio-fuels plants. This is an area where public resources and venture capital investments are needed. Nordic collaboration may provide solutions to challenges that currently seem impossible at the national level. Although venture capital investors have increased their attention towards alternative renewable energy during the last couple of years, the level of investments in the Nordic countries remains relatively small. Norway represents an exception in this context, especially if CCS is included. Norway is amongst the world's leading companies in CCS technologies and CCS ranks high on the political agenda. In this context we suggest that a Nordic venture capital fund for renewable energy be considered.

The Nordic dimension

The role of the Nordic countries' energy sectors could be strengthened by joint Nordic efforts. One issue is the bundling up of RD&D resources. The current collaboration about CCS at Mongstad is a good practice case where the Nordic countries are involved in addition to EU and other countries. The Nordic Council of Ministers should take the initiative and give funding to a Nordic Centre of Excellence in second-generation biofuels. Such a centre could build on the extensive expertise in the Nordic countries and could have great potential in contributing to a deployment at scales of this new generation of energy technology.

Lack of skills/human resources

The eNERGIA project has identified a shortage of engineers in relation to wind energy technology in Denmark and photovoltaic technology development in Norway in particular, but the lack of skilled personnel is a challenge that exists across Europe, in fact in most sectors. There is an urgent need to strengthen the education system, in particular the emphasis on science and technology subjects. This is necessary also for strengthening the absorptive capacity of the energy sector, i.e. the technology competence of the working force in the sector. Otherwise, new technological solutions will not find their way into Nordic and Baltic energy companies. Nordic policy should contribute to work that can deal with this challenge.

Critical mass

The Nordic and Baltic countries are all relatively small. It is a challenge for all countries, and in particular Iceland and the Baltic countries, to establish a needed critical mass in different technological domains. The challenge applies to research and the science base as well as to industrial activity. This is an area where the Nordic research and policy level could make a difference.

Knowledge sharing and knowledge using across borders

The established knowledge base in energy research and in relation to strategic planning of concrete investment processes may be of relevance across the Nordic countries. Nordic energy research and the Nordic energy policy level could improve the support of knowledge sharing and knowledge application across borders. Possible actions are the opening of national research programmes for the other Nordic countries and the establishment and funding of further Nordic centres of expertise in selected energy technologies.

Assessing environmental consequences

We have already emphasised the importance of establishing knowledge bases on environmental impact of renewable energy projects. This is an area where Nordic energy research has great potential of becoming a main driver, for example in funding of Nordic energy research collaboration projects on the environmental impact of renewable energy technologies.

Life Cycle Assessment (LCA)

Among the overall policy issues addressed in this project is the need for updated data that can be fed into the Life Cycle Inventory – the first step of LCA. There is urgent need for improvement of the data quality, enabling improved LCA. This is also a research area that should attract the attention of Nordic energy research.

Monitoring carbon storage

When it comes to the environmental impact of CCS, it is necessary to establish international regulations and monitoring procedures and monitoring research of carbon storage.

Joint action in biofuels

The Nordic countries have a strong knowledgebase in bioenergy and have the natural conditions and industrial capacity needed to become even stronger. This is a technological area that needs coordinated/joint action in research programmes that can feed into policy making.

Policy recommendations

For the technology fields focused on in this project we recommend the following measures:

Second-generation biofuels

The Nordic Council of Ministers should give priority to a joint action in second-generation biofuels. The council should substantially increase the funding for Nordic Energy Research, such as enabling Nordic Energy Research to support the establishment of a Nordic centre of excellence in second-generation biofuels.

Wind energy

The Nordic Council of Ministers should give support to a Nordic offshore wind research programme.

For Norway specifically, we recommend that the Norwegian Ministry of Petroleum and Energy establish a specific section specialised in wind energy under the Energy and Water Resources Department. In addition, the section for research and technology under the Climate, Industry and Technology Department should establish its own RD&D programme funding new renewable energy technology in collaboration with the Research Council of Norway. The programme should focus on offshore wind and other technologies recommended by the research strategy Energi 21.

Solar photovolatics

The already existing Nordic Centre of Excellence in photovoltaics should receive more co-funding by the national energy R&D funding agencies in the Nordic countries, such as the Danish Council for Strategic Research and the Danish Energy Agency, the Research Council of Norway, the Swedish Energy Agency and TEKES in Finland.

Carbon capture and storage

The Nordic Council of Ministers should give support to the establishment of a Nordic centre of excellence for R&D on carbon capture and storage. The Council should be more engaged in this topic, especially in the funding of R&D on carbon storage and in establishing international regulations and long-term monitoring of carbon storage sites. For that purpose the Nordic Council of Ministers should put more pressure on the European Commission. Carbon storage must be a matter of international agreements and under control of an international agency. For making carbon capture a possible option, several demonstration and full scale projects should be funded by Nordic governments. In addition, carbon prices have to increase dramatically for making carbon capture and storage an economic option.

General recommendations

The up-scaling of renewable energy projects is costly, and therefore we recommend the establishment of a Nordic Venture Capital Fund for Renewable Energy. This fund should give support to Nordic projects but should also co-fund projects in the least developed countries.

Funding of joint Nordic projects needs to be strengthened. Therefore, the funding of Nordic Energy Research should be increased and national R&D programmes in the Nordic and Baltic countries should be opened for co-applications from other Nordic and Baltic countries.

The Nordic Council of Ministers should introduce a common Nordic incentive mechanism for renewable energy. Such a system could be modelled on the Swedish scheme for electricity certificates. There is already a common understanding between Sweden and Norway for a common certificate market. We recommend the governments of Finland and Denmark join in the negotiations. A common Nordic certificate market could lay the ground for significant investments in renewable electricity in the Nordic region.