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Nordic Energy Research

Nordic energy innovation systems

- Patterns of need integration and cooperation

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Abstract: There are large potentials in employing the innovation system perspective to the energy area. Policy building on real insight in the innovation systems is until now seldom. This study gathers and discusses the knowledge about the Nordic energy innovation systems with special focus on the patterns of cooperation and of integration of needs with technological opportunities. In addition, the study investigates a row of innovation indicators. Four technology areas are in focus: bioenergy, hydrogen technology & fuel cells, solar cells, and wind energy. The study shows that the Nordic region is clearly visible in the general world picture of energy innovation. On many types of energy technology, the Nordic countries have leading competences. Energy innovation is a major activity area in Nordic economy. Nordic policy makers have obvious interests in the innovativeness and competitiveness of Nordic firms in the large global markets that are expected to grow fast. The Nordic energy innovation systems are characterised by multiplicity of actors and considerable cooperation and discussion across actor groups. The innovation systems on specific technologies are complex, historical constructions that are highly dependent on the specific industries and competence and resource bases they are anchored in. The innovation systems are significantly different from country to country and from technology to technology. It is needed that policy is strategically targeted and capable of taking the variations, the strengths and weaknesses in the individual technology areas, into consideration. Only thereby can ambitious policy be established. Opportunities for joint Nordic efforts are suggested.

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Executive summary

With globalisation tendencies and the increased market orientation and privatisation in the energy area, the perspective of innovation is becoming more and more relevant for understanding the dynamics of change and technology development in the field. A better understanding of the systemic and complex processes by which innovation occurs is useful and can constitute important background for policymaking. By adding the perspective of innovation systems to the more well-established policy perspectives of security of supply, sustainability, and efficiency in consumer prices, it can help make business development and entrepreneurial activities contribute to and go hand in hand with needed developments in the energy systems. Considerable synergies for reaching the energy policy goals can be obtained.

The innovation system perspective cannot replace the other perspectives in energy policy, but is an important addition.

The Nordic region is often clearly visible in the general world picture of energy innovation and energy technology development. Compared to its relatively small population size, the region accounts for a large share of the total energy innovation activities, for example in the area of bioenergy, where the Nordic region has a unique position with almost 30% of all biomass based generation of heat and power in the industrialised world and around 10% of the total scientific knowledge production, globally.

In the wind energy area, the Nordic industrial share of the world market is above 30%, the domestic markets constitute more than 5% of the total installations worldwide, and the scientific knowledge production is above 10% of global total. Also on other new energy technologies does the Nordic region have leading competences and positions, e.g. within solar cells, with around 3% share of the world market.

Energy technology development is big business. The global markets are expected to grow fast. Nordic policy makers and energy equipment manufacturers have obvious interests in the innovativeness and competitiveness of Nordic firms in the large future markets.

Already today, energy innovation is a large economy area and activity area in the Nordic region. It accounts for around 6% of the total revenues and employment in Nordic industry. Moreover, the exports of energy technology and equipment accounts for in the order of 5-9% of the total industrial exports. Another indication of that energy technology is not a small niche area in Nordic economy, but a main area, appears from the fact that many companies on the top-ten lists of the largest companies in the Nordic countries work with energy.

This study gathers and discusses the analytical knowledge about the Nordic energy innovation systems. The study contributes to new insight in the dynamics of the energy innovation systems especially with respect to characteristics of the patterns of cooperation and interaction in the innovation systems. Moreover the study investigates a row of innovation indicators for the Nordic countries. Through this it is the aim of the study to contribute to the policy development. Four technology areas are in focus in the study: 1) bioenergy; 2) hydrogen technology & fuel cells; 3) solar cells (photovoltaics); and 4) wind energy.

Innovation system studies have in the recent years shown that the conditions for development and innovation are not identical across geographical and national borders but differ according to the specific constitution of the learning, knowledge production, and institutional set-up in the countries and in different industrial sectors. Differences between the competitive and innovative strengths of countries can be ascribed to differences in the patterns and dynamics of learning and knowledge production. This is the case in the energy area as well as it is in other sectors.

A key aspect in the learning interaction in innovation systems is the integration between on the one hand the needs and demands for new energy solutions and new energy systems and on the other hand the technological and scientific opportunities, potentials, and visions. This is what we call the processes of *need integration*. The Nordic countries have with a relatively strong tradition for co-operation, societal

engagement, and discussion across actor groups an advantage compared to many other countries with respect to need integration.

Ten policy lessons and four Nordic opportunities

We condense the findings of the analysis in ten lessons for policy makers. In addition we suggest four specific opportunities for joint Nordic efforts that would be valuable to pursue in the coming years.

The first and most general conclusion of the analysis is that the energy innovation systems in the Nordic countries are not identical and homogeneous across the national borders but vary considerably with respect to amongst other things institutional structures of the energy sectors, dominating technology regimes, natural resources and environmental challenges. Also with respect to each individual of the new energy technologies addressed in the study, are the innovation systems highly diverse.

There is no such thing as a common Nordic energy innovation system. To some extent, the bioenergy area is an exception to this general picture, with relatively significant cross-border connections, not least between Finland and Sweden, but also more broadly.

The diversity in the innovation systems implies diversity in policy efforts. The **first** policy lesson is that policy makers should be aware of the variations of the innovation systems and capable of taking the differences into consideration in the policy efforts. More specifically, it is needed to maintain a ‘strategic intelligence’ (i.e. knowledge and insight) on the specific innovation systems and the individual technology areas at the ministries and other public authorities that help governmental development of the energy policy.

The **second** policy lesson is to pursue a policy that involves and is in dialogue with all relevant actor groups. This point build on a second general main finding of the analysis: that it is characteristic for the Nordic energy innovation systems that there are many different types of actors involved in the innovation systems. It is not only, say, industrial companies and research institutions, but also for example branch organisation, environmental NGOs, public authorities, etc., that define the systems. The many involved actors constitute a stronghold for Nordic energy innovation. A narrow understanding of the actor set-up in the innovation systems does not give an adequate understanding of the systems and the innovation dynamics.

The **third** policy lesson is to consciously involve application based learning (learning-by-using/learning-by-doing) in a strategic way in the innovation and energy policies. Do not only focus on learning through formalised, academic knowledge production, but make learning-by-using/learning-by-doing and formalised knowledge production support and enforce each other.

Integration of needs and demands through regulation are important in many of the technology areas addressed. This is not least the case in the areas where we have actually seen important changes and significant developments of the energy systems in connection with the technology developments. Indeed, policy and regulation can be considered the single most important driver for innovation in the energy area. This is a **fourth** lesson. To set up ambitious goals and requirements to technology development through policy and regulation is crucial for high-quality energy innovation.

In continuation of this it is a **fifth** policy lesson that there is considerable potential for improvement of the innovative impact of market-oriented policy efforts. Only in a few of the cases where we have seen policy efforts that are supporting market formation, price structures, etc. do we see significant innovative learning and build-up of competences as a result. The timing of the policy efforts, and not only the amount of the economic support, can often be important.

The Nordic energy innovation systems are characterised by a considerable amount of cooperation. On this point the analysis however also shows that there are significant differences between the technology areas. The innovation systems on solar cells and on hydrogen and fuel cells appear to be relatively scattered and disconnected. It is the **sixth** policy lesson that programme managers as well as policy makers more generally should look for possibilities for improving the cooperation between the actors especially in these two areas.

The innovation systems of the energy area reflect the general, national innovation systems of the Nordic countries, amongst other things concerning cooperation and interaction patterns, but also on other points. It is the **seventh** policy lesson that policy makers should be aware of this embedment and the advantages and limitations this can imply.

It is an important finding of the study, that innovation of new energy technologies usually is strongly connected to and anchored in existing industrial bases and competences in the countries. In the cases where we see strong industrial clusters emerging on energy technologies, like, e.g., bioenergy in Finland, Sweden and Denmark, solar cells in Norway, and wind energy in Denmark, the connections to existing industrial bases are significant.

The **eighth and ninth** policy lessons are on the one hand that it is important for policy makers to develop an awareness of the industrial competence bases of the countries and to identify opportunities for diversification into new areas based on the existing competence bases.

On the other hand, that embedment in the competence base of the existing energy sector can often also be a limitation and a barrier for energy innovation. Policy makers cannot expect that large energy companies lead the way in the development and diffusion of all types of new energy technologies. On the contrary, it must be expected that they will be most inclined to go for technologies that build on their existing competencies and assets. If policy makers aim to stimulate a departure from these trajectories, they will need to provide alternative spaces in which the new technologies can thrive and develop.

In addition to the bases in industrial competences also the base in the available natural resources is of importance to the energy innovation systems. The analysis shows that also on this point, the base can both be an opportunity and a barrier for change. The exploitation of the opportunities inherent in the current competence bases takes place in a context where there are inherent risks of lock-in from the resource base. This is the **tenth** and final overall policy lesson of the study.

Additional points about the innovation systems with respect to the individual technology areas, and their strengths and weaknesses, can be found in the country chapters, in the comparative tables in Chapter 7, and in the extensive appendices of the report.

With the relatively different and separate energy innovation systems in the Nordic countries it does not seem feasible to establish one, common Nordic policy effort generally on innovation in energy technology. A strategy of supporting more delimited areas can be chosen. The analysis points to four such areas, related to the technology areas in focus in our study. The list must be considered tentative. Also other areas might be considered. The four suggested areas for joint Nordic efforts are:

- **Gasification of biomass.** The Nordic countries have built up a considerable stock of knowledge and practical experience on gasification technologies for biomass and Nordic actors have leading competences on a number of points, both concerning gasification of materials based on wood and on materials from agriculture and farming. Networks in the Nordic countries already exist to an extent. A Nordic effort for market application, knowledge development and networking can be of significant importance for the chances of establishing the field as an industrial cluster with strong competitive advantages. Timing is here essential as clusters are being built up abroad, in particular in Germany and Austria.

- **Nordic bioenergy cluster and export of bioenergy technology.** The relatively well-established innovation system on bioenergy with world leading positions on application and knowledge production and with considerable networks between Nordic countries, can through a supportive effort be developed towards an actual industrial cluster of international strength. This requires a stronger emphasis on business development, industrialisation and export of bioenergy technology than until now. The effort could more specifically consist in two legs: An effort for identification of export markets and exploration of export opportunities. And an effort for continued networking and information exchange about industrial competences, application experiences and potentials of new and advanced areas of scientific knowledge in connection with bioenergy.

- **Integration of solar cells in construction industry and buildings.** The application side and domestic markets of solar cells in the Nordic region are relatively weak. Yet, this is one of the most promising technologies in the longer term and the technology is currently being industrialised on a large scale in Germany. The low integration in the construction industry and building traditions is one of the main gaps in the Nordic innovation systems. A joint Nordic strategic effort for integration of solar cells in the construction industry and in building components may, therefore, be justified. Focus would be on knowledge development, demonstration projects and larger market formation programs as well as experience exchange that can bypass the shortcomings of the project-based (i.e. scattered) tradition within construction. Through the effort, Nordic industry can benefit from a demanding home market. In addition, the Nordic countries can influence the development of standards and certification/labelling systems on international level.

- **Nordic markets, networks and competences in the wind energy area.** With the strong Danish wind turbine industry and the important sub-supplier networks in the Nordic countries, support of new emerging competence areas within e.g. turbine components, system integration technology, offshore technology, project development and planning, could lead to important synergies and further strengthening of the Nordic innovation system. In particular, this applies to the promising and huge off-shore market which could be the base on which the Nordic innovation systems could expand.

The study identifies a large number of quantitative figures as indicators of innovation in the energy area. The analysis however also points out that the field of innovation indicators in the energy area is a field that needs to be developed further. Only limited bodies of comprehensive and comparable data exists. For example with respect to venture capital and risk investments and with respect to private sector’s research and development expenditures it has not been possible to find reliable data sets.

1. Introduction: Energy and innovation systems

1.1 Energy seen as area of innovation

Change in the energy sector has for many years been considered a public matter only: a question of public policy in interplay with energy institutions, which were most often also public. In recent years this picture has changed. It is now the understanding that initiatives and activities by other actors, e.g., industrial companies, researchers, innovative entrepreneurs, NGOs, etc. can contribute importantly to developments in the energy sector. One reason for this new situation is the liberalisation and increased market-orientation in energy policy as well as in policy more generally. This has moved emphasis to other actors than government. Another reason is the increased internationalisation amongst other things of trade and production, including energy trade and energy production, and of technology and knowledge development. This makes it more difficult for national governments to control and steer processes of change and technology development.

Thirdly, it has become apparent that there are considerable potentials for economic development through development of energy technology and solutions for new, sustainable energy systems. There is money in energy. Not only in selling energy products like oil, gas, electricity, etc., but also in selling equipment, solutions and technologies for energy production. A major part of the value increment in energy systems appears in the supply of production technology and equipment (Hvelplund 2007). Examples of significant industrial developments in areas of energy technology have occurred and the demand for sustainable and climate friendly energy technologies is rising in many countries.

Together these tendencies mean that there is now a stronger focus on the energy area as an area of industrial development and innovation in complex processes between public and private actors. Efforts for transforming the energy systems towards sustainability often go hand in hand with business development and commercial activities, at least to some extent.

Policy building on real insight in the energy innovation systems is still seldom. However, for example, the European Union has with its 'Lisbon Strategy' defined on an overall level that economic development and competitiveness is an important part of the move towards sustainable development and reduction of the environmental problems. This has been specified further, e.g., in the European Strategic Energy Technology Plan (SET-plan) and the EU Environmental Technologies Action Plan (ETAP) where environmental and climate protection, technological innovation and competitive economic development are seen as integrated elements. With the launch of these two plans the energy and environmental policies are sought aligned with policy goals for innovation and competitiveness.

In recent years, a number of analytical studies of the energy innovation systems have appeared. For the Nordic countries these e.g. address bioenergy and combined heat & power in Finland, solar cells, bioenergy, and wind energy in Sweden, fuel cells and oil & gas in Norway, and wind energy and bioenergy in Denmark.

This report gathers and discusses the analytical knowledge about the Nordic energy innovation systems. The study contributes to new insight in the dynamics of the energy innovation systems, especially with respect to characteristics of the patterns of cooperation and interaction in the innovation systems. Moreover the study investigates a row of innovation indicators for the Nordic countries. Through this it is the aim of the study to contribute to the policy learning, building on the perspective of innovation systems.

Before describing the innovation system perspective and the analytical approach more in detail in Section 1.2 and 1.3, a few overall figures and innovation indicators are presented.

Nordic energy technology in the world economy - and in the Nordic economy

The Nordic region is often clearly visible in the general world picture of energy innovation and energy technology development. Compared to its relatively small population size, the region accounts for a relatively large share of the total energy innovation activities of the world.

This can be seen for example in the area of bioenergy, where the Nordic region has a unique position. Almost 30% of all biomass based generation of heat and power takes place in the Nordic countries. Around 10% of the total scientific knowledge production on bioenergy stems from the region (see Appendix B.4 for details). Although, it has not been possible to find reliable data for a quantitative indication of the Nordic industries' share of the total supply of technology and equipment for biomass heat and power, it is estimated that the share is relatively high. The Nordic region has leading suppliers of both biomass power plants as such and of central key components like e.g. boilers.

Also on other new energy technologies for sustainability the Nordic region is clearly visible in the general world picture. The Nordic region has a significant position in wind technology. The industrial share of the world market for wind turbines is above 30%, as shown in Figure 1, the column to the very right. Concerning the domestic market (Market indicator – installed capacity of wind turbines until end of 2006), the Nordic region has a more modest international position. Still it is more than 5% of the total installations worldwide. The science system indicators (papers, citations and patents) are all above 10% of global total, as is the governmental R&D spending. The position in wind energy is primarily constituted by the Danish wind energy cluster. However, also companies in Finland, Sweden and Norway play important roles in the industrial networks, not least as sub suppliers and manufacturers of components.

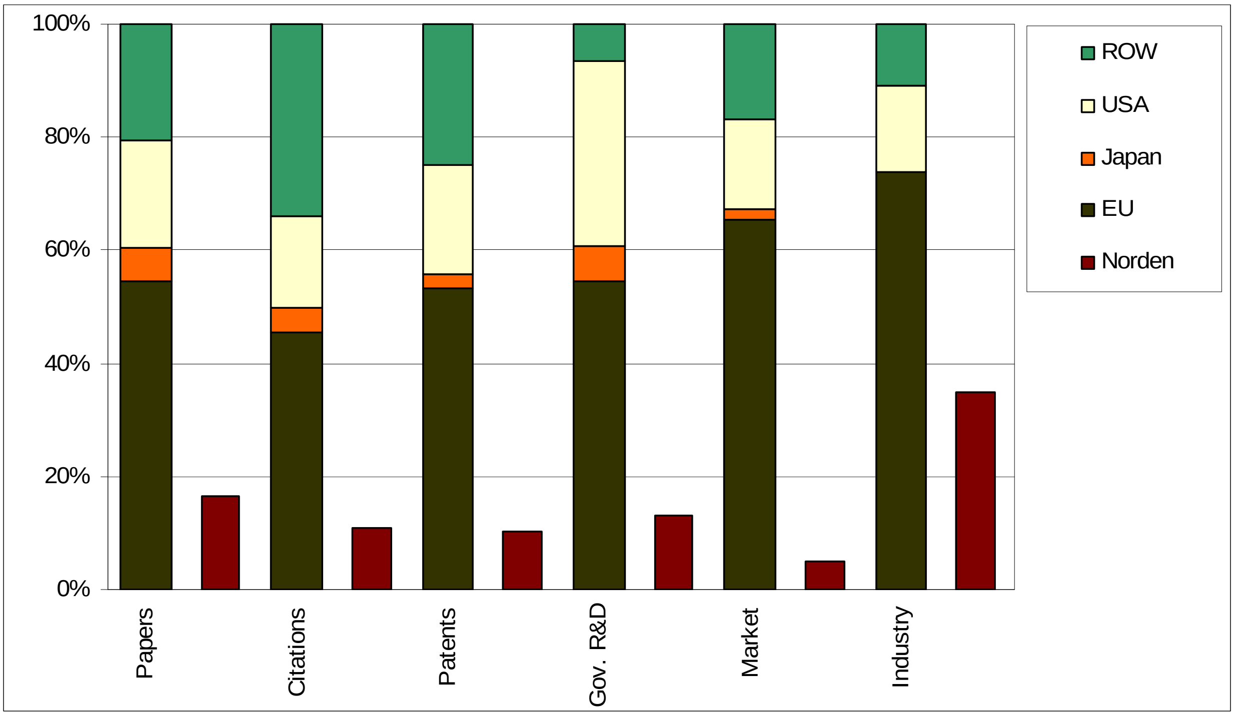


Figure 1: Set of innovation indicators for wind energy – the Nordic region compared to the world. Sources (years covered is shown in brackets): Scientific papers and citations (1996-2006): Science Citation Index (Web of Science); Patents (1996-2006): Derwent World Patents Index; Governmental R&D (1996-2005): IEA R&D statistics; Market and Industry indicators: Installations and manufacturing of wind turbines (2006): BTM Consult 2007. ROW means Rest Of the World. See Appendix B for details.

Figure 2 shows a similar set of innovation indicators for solar cells (photovoltaics). Here the Nordic region has in general a much smaller share of the worldwide activities than in bioenergy and wind energy. However, while the domestic markets (measured in terms of installed effect) and the governmental R&D funding are too small to appear clearly in the global perspective, the industry indicator shows that the market share of Nordic industrial companies producing solar cells is in the order of 3% of the world market. Norwegian REC/ScanCells stands for a major part of this. In addition, the indicators of formalised knowledge production - scientific papers and citations – show a significant Nordic contribution, while Nordic patents only counts for around 1% of the total.

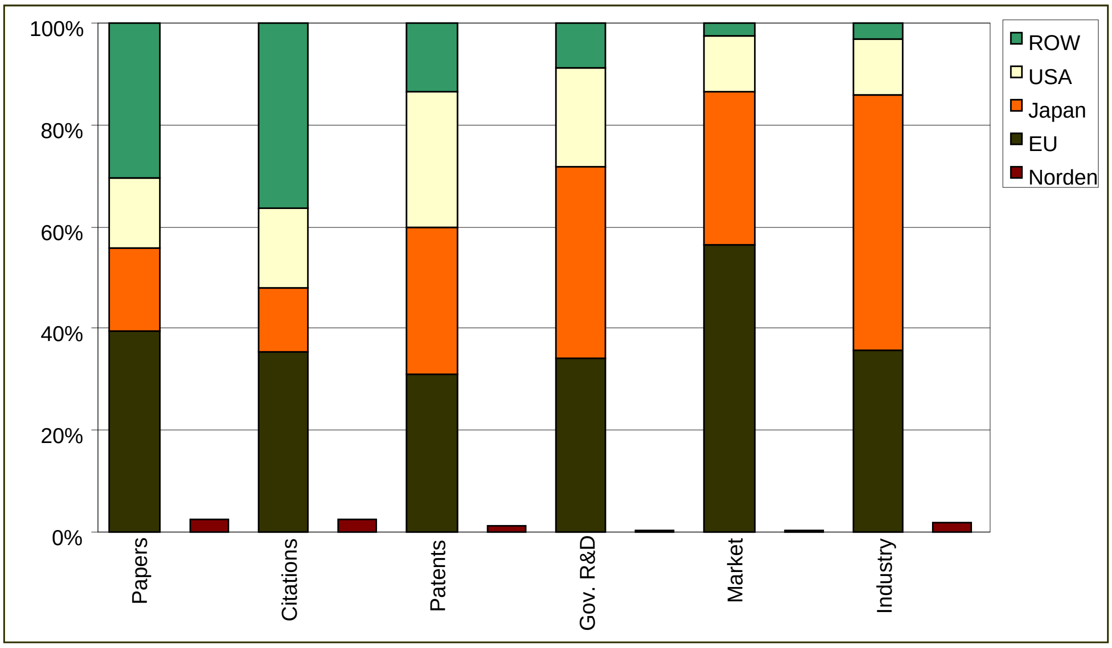


Figure 2: Set of innovation indicators for solar cells (photovoltaics) – the Nordic region compared to the world. Sources (years covered is shown in brackets): Scientific papers and citations (1996-2006): Science Citation Index (Web of Science); Patents (1996-2006): Derwent World Patents Index; Governmental R&D (1996-2005): IEA R&D statistics; Market: accumulated installed capacity of PV measured in MWp by the end of 2006. Sources: IEA-PVPS Trends in Photovoltaic applications (2007) and EurObserv'er. Industry: Solar cell production in MW during 2006. Source: http://www.iea-pvps.org/. This indicator does not take not into account supplying industries. See Appendix B for details. ROW means Rest Of the World.

Sets of innovation indicators for Nordic activities also on biofuels for transport, hydrogen technology and fuel cells can be found in Appendix B. An overview of the Nordic position with respect to domestic market and scientific knowledge production (combination of papers, citations and patents) is shown on Figure 3.

Energy technologies are big business. The International Energy Agency (IEA) estimates that the cumulative investments in energy supply infrastructure amounts to 21 trillion USD (21000 billion) in the period 2005-2030. Europe's share of this is 2395 billion USD (IEA World Energy Outlook, 2006, reference scenario, p77). In the same period it is estimated that the number of people working with sustainable energy technologies will increase to more than tenfold as many as the 2.3 million it is today (UNEP et.al. 2008). Europe is seen as a leading player on a global level in the development of sustainable energy systems.

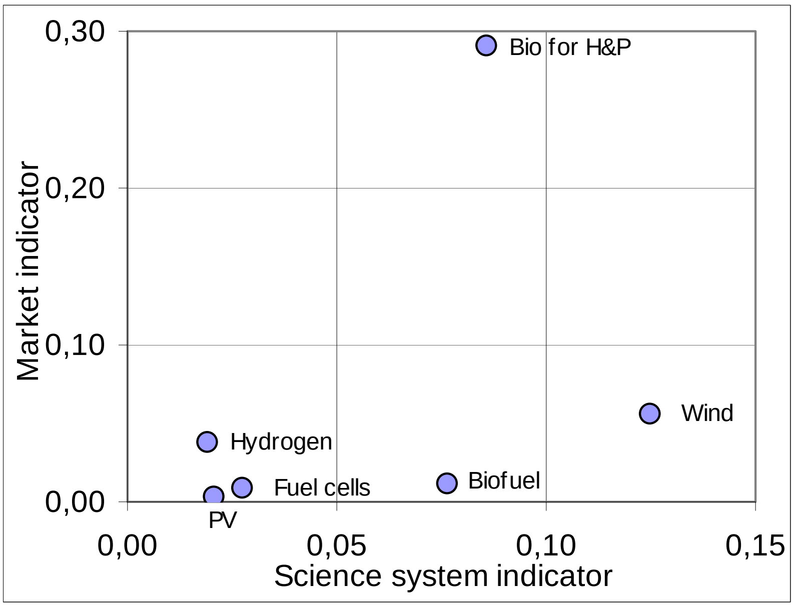


Figure 3: Overview on the Nordic position in six energy technologies.
See text for explanations and Appendix B for further details.

Also for the Nordic countries, energy technologies are big business and a large area of activity. Nordic policy makers and energy equipment manufacturers have obvious interests in Nordic firms' innovativeness and competitiveness in the large future market for energy technology. The energy technology industry in the Nordic countries is in total estimated to have revenues of € 26 billion, corresponding to 6.2 percent of the total revenues of the Nordic countries' industry. The energy technology industry has around 108 000 full time employees, corresponding to 6 percent of the total number of full time employees in the industry in general in the Nordic countries (Trong 2007).

Exports of energy technology from the four largest Nordic countries amounted in 2006 to around 140 billion DKK in 2006 (Trong 2007). As appears from Figure 4 the exports were highest from Sweden and Denmark with 45-50 billion DKK. In all the countries the exports of energy technology have increased significantly in the latest years, with growth rates between 2005 and 2006 on 26 percent for Finland and 18 percent for Sweden and Denmark. The growth rate for Norway was only 3 percent from 2005 to 2006, however around 7 percent a year in average if one considers the ten-year period from 1996 to 2006.

The exports of energy technology and equipment constitute a considerable share of the total exports from the Nordic countries. It is thus among the most important areas of exports in general. For the countries taken together, the exports of energy technology and equipment are in the order of 5% of the total exports, highest in Denmark with more than 8% of the total exports in 2006 and more than 9% in 2007 (Energistyrelsen 2008). The large increase in the latest years is primarily due to the wind energy area. Though also Norway, Sweden and Finland have experienced increase in the exports of energy technology in the latest years, it has for the two latter countries, as the figure shows, in the period 2000-2005 not been larger than the general increase in exports.

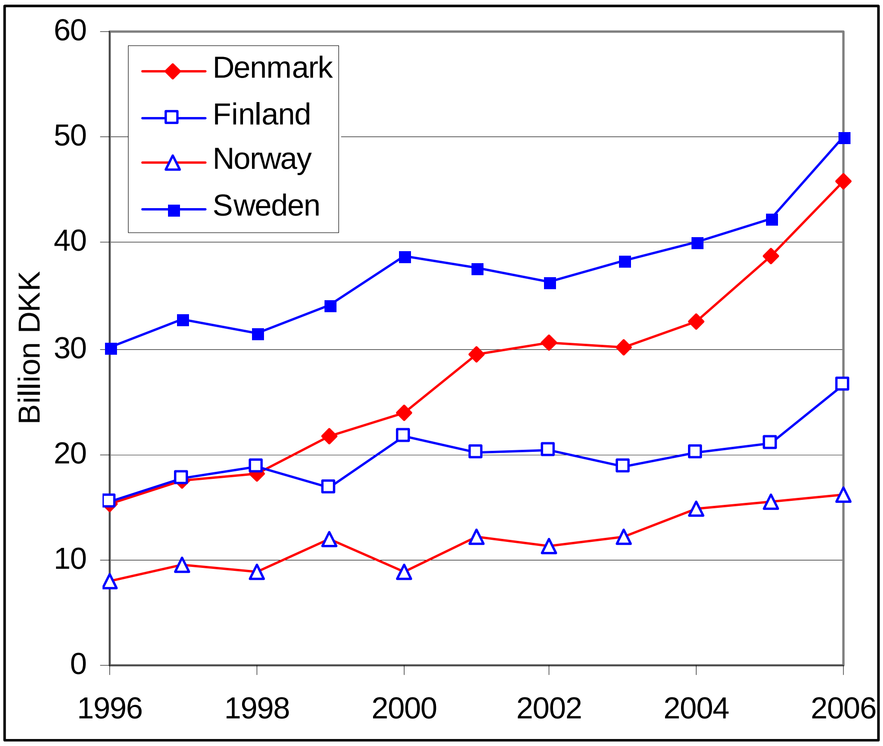


Figure 4: Development in exports of energy technologies from the four larger Nordic countries. Danish Energy Authority, www.ens.dk/sw48374.asp, based on data from EUROSTAT (COMEXT) and DI Energibranchen. Data for Norway: Trong (2007) based on data from Statistics Norway.

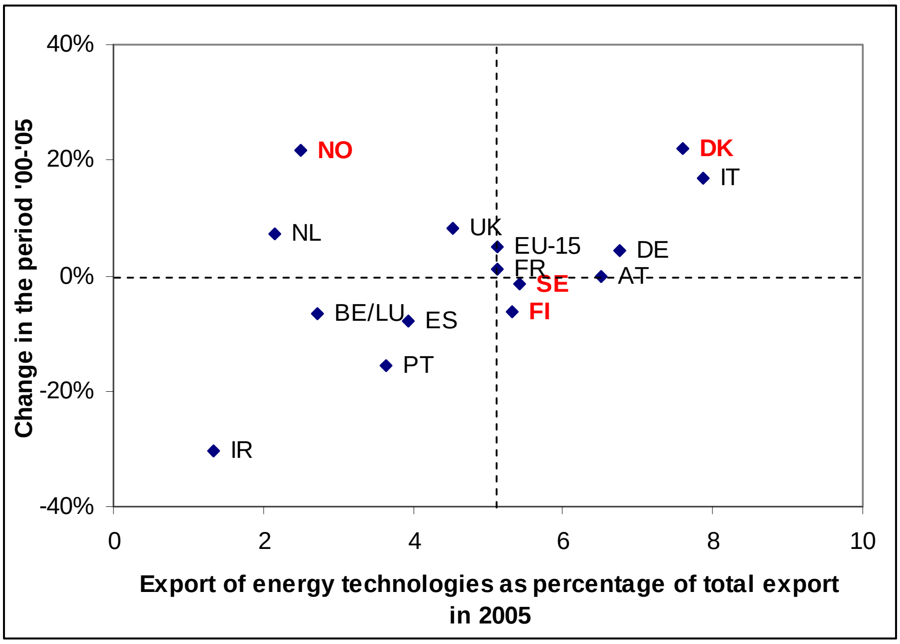


Figure 5: Export of energy technologies and equipment. Sources: Danish Energy Authority, www.ens.dk/sw48374.asp, based on data from EUROSTAT and Statistics Denmark. Data for Norway: Trong (2007) based on data from Statistics Norway.

A further indication of that energy technology is not a small niche area in Nordic economy, but a major area with a considerable amount of activities appears from top-ten lists of the largest companies in the Nordic countries (Figure 6). It is clear that energy is not solely of interests for small and medium size firms or small university start-ups. The lists of firms of course reflect the general industrial structure of each country. In Denmark agriculture and foodstuff related firms occupy 3 out of the ten largest firms: Arla Foods (milk), Carlsberg (beer), Danish Crown (meat). But energy related activities are also important. DONG Energy is both an oil and gas producer and producer of electricity. Vestas is the world's largest wind turbine manufacturer. A.P. Møller – Mærsk is a conglomerate based on sea transport and retail but also on oil & gas production.

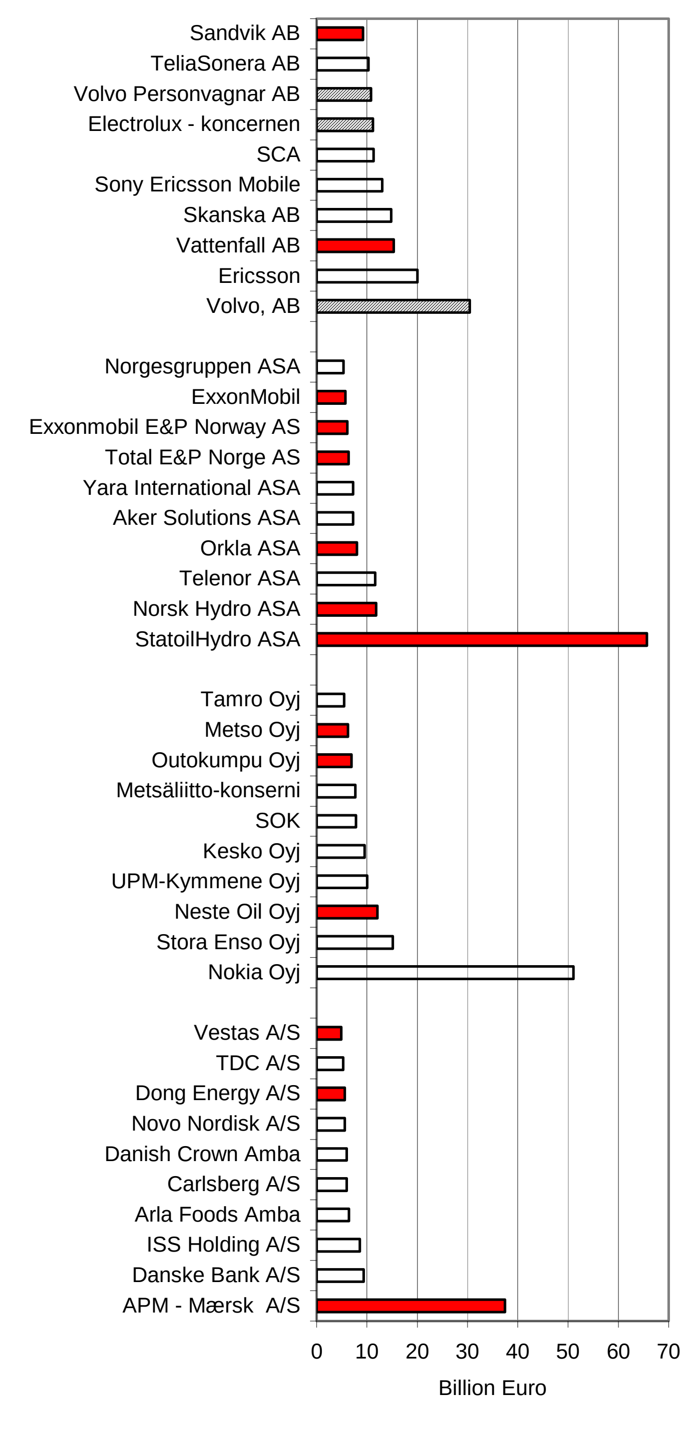


Figure 6: The 10 largest firms in each of four Nordic countries: from the bottom; Denmark, Finland, Norway and Sweden. Source: largestcompanies.com provided by Nordic Netproducts AB. Data is based on largest companies by turnover (excl. subsidiaries) and on 2007 financial reports. Red bars indicate energy related businesses.

In Finland paper, pulp and forest products dominate the top-ten list with firms such as StoraEnso, UPM-Kymmene and Metsäliitto Group. To that can be added Metso that produces machinery for the pulp and paper industry. Neste Oil has of course its main activities in the energy sector, but also other top-10 firms in Finland have activities in energy and energy technologies. Metso's Automation division serves customers in energy, power and process industries, for example related to boilers for biomass. Outokompu, which has its main business within stainless steel, has energy related products such as LNG road tankers and LNG pipelines. Outokompu participates with, e.g., Swedish universities in R&D activities related to solar cells.

Norway's economy is dominated by production of oil and gas. Half of Norway's 10 largest firms relates to the oil and gas sector. This also includes Norwegian subsidiaries of large international oil/gas firms such as Total and ExxonMobile. The leading Norwegian oil and gas companies are also involved in renewable energy. Norsk Hydro is involved in R&D in areas such as hydro power, wind power, bio fuels and Carbon Capture and Storage (CCS). StatoilHydro is involved in wind power, and a branch of Orkla, Orkla Engineering, is involved in R&D within Carbon Capture and Storage.

The 10 largest firms in Sweden are larger than most of the firms in the other three countries. This demonstrates that Sweden's economy is based on large classical industrial manufacturers in sectors such as cars and trucks (Volvo), telecommunication (Ericsson, SonyEricsson, TeliaSonera), and home appliances (Electrolux). Vattenfall is one of Europe's largest producers and distributors of electricity and heat. Sandvik has a division targeting materials technologies for the oil and gas industry (e.g. heat exchangers and pipelines for oil and gas processing. Volvo is an active player in

Nordic and European energy related innovation – for example in relation to biofuels, hydrogen and fuel cells. Large Swedish firms just below the top-10 list are also involved in energy related R&D. ABB is involved in generators for wind power and in photovoltaics. SKF is a leading supplier of bearings for wind turbines.

Beyond the mentioned energy related firms a lot of Nordic firms has strategic interests in the energy sector either as large consumers of energy (like the Finnish and Swedish materials and paper & pulp industries) or as producers of energy end-use products (such as Electrolux).

1.2 Analysis of innovation systems[1]

Over the latest 15-20 years the analytical-theoretical approach of innovation systems has been established as a popular and often used analysis approaches within evolutionary economics and innovation studies in general, as well as in policy-supporting innovation analyses specifically.

The studies of innovation systems have shown that the conditions for development and innovation are not identical and homogenous across the world but differ from country to country and from region to region (Lundvall 1992, Nelson 1993, Edquist 1997, Edquist & Hommen 2008). Differences between the competitive and innovative strengths of countries and regions can be ascribed to differences in the specific constitution of the knowledge production, the learning dynamics, the institutional set-up and the industry structures. The differences exist despite globalisation, more open markets, and expanding international networks.

The innovation system literature points out that the innovative performance is a matter of systemic interactions between many different activities and interactions between actors of different kinds. This can be illustrated by the schematic figure below. Synergies on the systemic level between the different activities are decisive for whether there is a degree of efficiency in the innovation systems.

The capability of change and innovation can usually not be explained by one factor alone, e.g. by science and research alone, or by market forces alone, or by policies and institutions alone. The system character of innovation systems refers to the fact that development and innovation appear in interplay between different actors e.g. companies, their customers and suppliers, research and educational institutions, authorities, interest organisations etc. It not only depends on the capabilities and resources of the individual actors. Patterns of co-operation are a key aspect.

Conditions for the developments are influenced by labour markets, educational systems, industrial structure, competitive regime, regulation, collaboration, etc. The strengths of the innovation systems depend on whether there is a kind of efficiency in the systemic interplay where synergies between different activities are gained.

Informal and formal knowledge production (learning) is the central, general activity in innovation systems. Thus an innovation system can be defined as “the elements and relationships, which interact in the production, diffusion and use of new and economically useful knowledge” (Lundvall 1992, p. 12).

In addition to formal knowledge production, e.g. at universities and research institutions, innovation system studies have pointed to the importance of informal knowledge production, e.g. knowledge gained through practical work, experiments, prototyping etc. (learning-by-doing) and knowledge gained in interaction with markets and users (use-driven innovation; learning-by-using (Lundvall 1992), lead users, lead markets (von Hippel 1988)). Learning-in-interaction is in general important in innovation systems e.g. between industry and research, between manufactures and suppliers. The significant importance of tacit knowledge as part of the explanation of the context-dependent character of innovation systems is obvious (Polanyi 1966).

A key aspect in the learning interaction in the innovation systems is the integration between on the one hand new technological and scientific opportunities and on the other hand needs and demands for, e.g., in our case, new energy solutions and new energy systems. This can in short be called the processes of *need*

[1] Parts of this section draw much on (Borup, Gregersen & Madsen 2007).

integration. The strength of an innovation system is to a considerable degree shaped by the efficiency of and the efforts for a substantial integration of the needs and the technology opportunities. Analyses in the energy area as well as in other areas have shown that it is a central challenge for innovation and for innovation policy to connect technology push, R&D support and other supply side efforts with demand side efforts (Walz et.al. 2008, Markard & Wirth 2008). We will return to need integration later in the chapter.

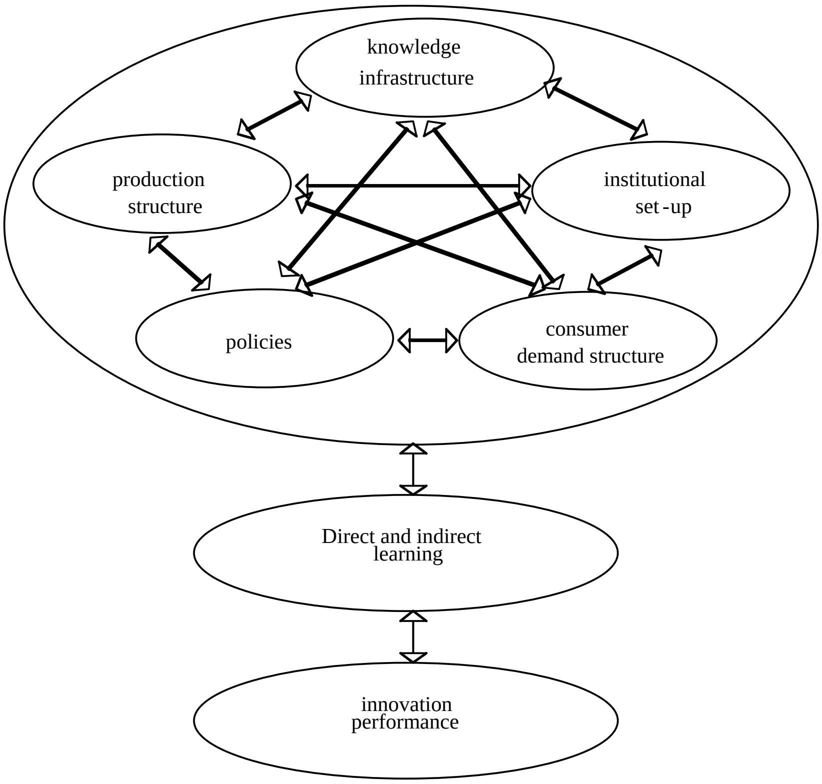
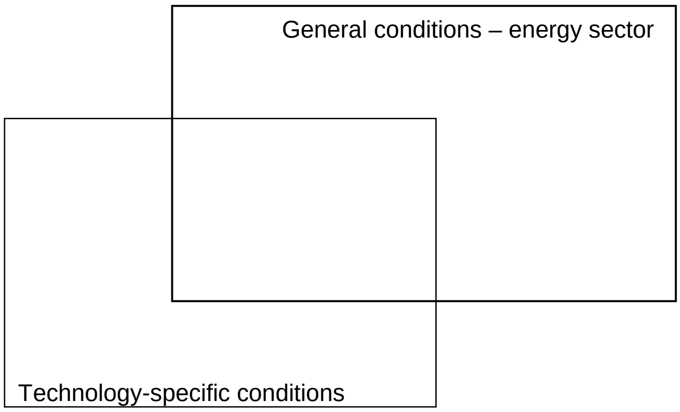


Figure 7: The innovative performance of an innovation system (Gregersen & Johnson 1997).

Technology-specific innovation systems

Energy technology development is to a large extent influenced and shaped by the conditions in the energy sector in general. Often development of new technologies however also to some extent transcends the limits and borders of the existing energy sector and integrates knowledge and perspectives from other fields. The networks of the technology developers reach outside the sector. Especially when we, as we do in this report, look at new energy technologies that aim at contributing to a transformation of the energy systems towards sustainability, it is clear that other resources than those from the well-established energy sector will in many cases be drawn upon. A simple illustration of this is shown in Figure 8.

Figure 8: Illustration of the conditions for energy technology development: a combination of the general conditions of the energy sector and technology-specific conditions.



Of the different branches within innovation system analysis, the technology-specific approach has often been applied to the energy area (Jacobsson & Bergek 2004, Hekkert et.al. 2006).[2] In the analyses technology-specific innovation systems it is pointed out that there are significant differences between mature technology areas where the technology systems are relatively well-established and dissemination of the technology to a considerable degree takes places through marked-based interactions, and immature areas of emerging technologies where the innovation systems with respect to the technology have formative character. Like in all innovation systems, actors, networks and institutions are of central importance. However in immature areas, there usually are relatively few actors, more scattered networks, and less developed institutions compared to mature areas.

In reaching well-established, new technology systems a number of typical activities, or ‘functions’ in the innovation system have been identified as important. The functions are (following Jacobsson & Bergek 2004):

1. Knowledge production and diffusion; including entrepreneurial experimentation and learning

2. Guidance of the direction of search processes; i.e. explicit policies, strategies and vision creations (legitimation) as well as implicit and tacit expectations in the knowledge developments

3. Formation of markets; i.e. definition, development, institutionalisation and regulation of markets – often also development of niche markets and niche applications

4. Mobilisation of resources; competences, labour and financing

5. Creation of positive external economies; including e.g. establishment of new business areas, development of industrial structures and sub-supplier networks, supporting service systems, consultancy business, etc.

The functions are overlapping and should not be understood as mechanical or functionalistic building blocks. Moreover, the functions are activities considered on a very general level. The specific interaction patterns and development dynamics can within these functions take on many shapes. However, the point is that functions generally appear in connection to the development of a new technology area, at least if the technology becomes of any broader significance. That is, if it becomes successful and obtains widespread application, and maybe, ultimately, changes the existing technology regimes in the sector.

[2] There are four branches of IS analysis. In addition to the general (national) approach and the technology-specific approach mentioned above, there are also a regional approach (Cooke 2004, Storper, Asheim & Gertler 2004) and a sector specific approach (Malerba & Orsenigo 1997, Malerba 2002).

Policy building on innovation system studies

Policy building on the innovation system perspective can consist in various types of efforts, both assessment of existing innovation systems, their elements and coherence, and constructive efforts supporting development of the innovation systems. Until now, policy building on real innovation system insight is seldom in the energy area. The constructive policy efforts can either be efforts that improve the general framework conditions for the innovation system, e.g., concerning resources like finances, education, and labour market, or efforts that support the effective inner 'working' of the innovation system.

The latter can consist in identifying gaps or weak elements in the innovation systems and try to support improvement of these, or in identifying relative strong elements in the systems and see how these can be made drivers of broader developments in the systems. Further, the efforts can consist in asking whether there are sufficient connections and synergies between the different activities in the system or they appear disconnected and scattered, and if so, how can the synergies and comprehensiveness be increased.

More specifically this can for example consist in looking at whether different types of learning and knowledge production occur: scientific and formalised knowledge production, practical experience building from using and experimentations, learning from industrial production, from market dissemination, etc., and whether the different types of learning and knowledge production are connected and integrated with each other. Connections between on the one side consumers and the use context and on the other side producers and developers are important. This is one of the ways were the actual needs are directly integrated with the technological development and innovation activities.

Another central dimension is whether there are established markets and market dynamics that signal clear incentives for innovation and whether there are connection and synergies between market-based learning and learning from non-market interactions.

Also other of the overall functions mentioned above could naturally be addressed by policy, including whether new business activities and new industrial network (positive external economy) appear or can be encouraged and whether the shared visions, strategies and legitimation among actors are robust and strong enough to guide experiments and development activities in wanted directions.

Policy building on the innovation system perspective is hence policy with a comprehensive and systemic view on technology development and innovation. It recognizes the very complex character of innovation, technology development and of change in the energy sector more broadly.

No best working of an innovation system exists. There is not only one, single optimal way an innovation system can be organised and structured. Policy efforts can therefore not be defined exclusively in general terms and by general policy instruments only, but must always be shaped by the specific characteristics and the specific context of the area considered.

This also means that policy building on an innovation system perspective will usually not consist in establishing new innovation systems from scratch. Innovation systems are highly complex and large entities that grow out of a specific historical context and build on norms, routines and structures from existing practice fields, industries and knowledge areas. To establish a completely new innovation system will normally be too complex and resource-demanding task for a limited policy effort.

Among the pitfalls that should be avoided in policy building on innovation analysis is among other things a too narrow understanding of the innovation system where the system is seen as consisting in only a network of public research-supporting institutions like, e.g., ministries, R&D programmes, research councils, innovation-support institutions etc. Such view would often overlook central parts of the innovation dynamics.

Of other pit falls that shall be avoided is a linear understanding of development where technology development and innovation is seen as starting in scientific laboratories, and in subsequent phases move to demonstration, industrial product development, market diffusion and final application. Usually the interaction between research and other actors is much more complicated and goes in both directions.

To this comes the pitfalls of seeing innovation itself too narrowly, e.g. as being only a matter of creativity and new ideas (there are huge amounts of creativity 'out there', ideas are not a scarce resource), or as a matter of commercialisation and business development only.

Need integration – meetings of technology visions and practical needs

As mentioned above, a key aspect in the learning interaction in innovation systems is the integration between on the one hand the needs and demands for new energy solutions and new energy systems and on the other hand the technological and scientific opportunities, potentials, and visions. This is what we call the need integration.

Needs integration: The complex interaction between

Technology push ⟷ Demand pull

Need integration happens through a complexity of many different processes, for example through formalised co-operation in user-producer relations and supply-chains, through policy definition and legislation, and through informal interactions in networks, discussion forums, media etc. In the present study, we address need integration boiled down to three overall categories of processes:

1. Integration by using (learning by using; user-driven innovation)
2. Integration through public discussion and networks
3. Integration through regulation and planning

There are indications of that the Nordic countries with a relatively strong tradition for co-operation and discussion across actor groups have an advantage compared to many other countries with respect to need integration. Some of the reasons for this have to do with general cultural characteristics: The power structure is relatively flat in the Nordic countries and there is tradition for reflective practice and discussion; not only for individual action (see figure 10).

Concerning knowledge development, the cultural characteristics also show in not only a high degree of education in general, but also in a less discipline-restricted knowledge understanding than in many other cultures. This is in favour of a more learning-oriented understanding, where one can continuously learn new things from others and where there is relatively much weight on interdisciplinarity. Compared to other countries, a relatively large share of the population is engaged in life-long learning, see Table 1.

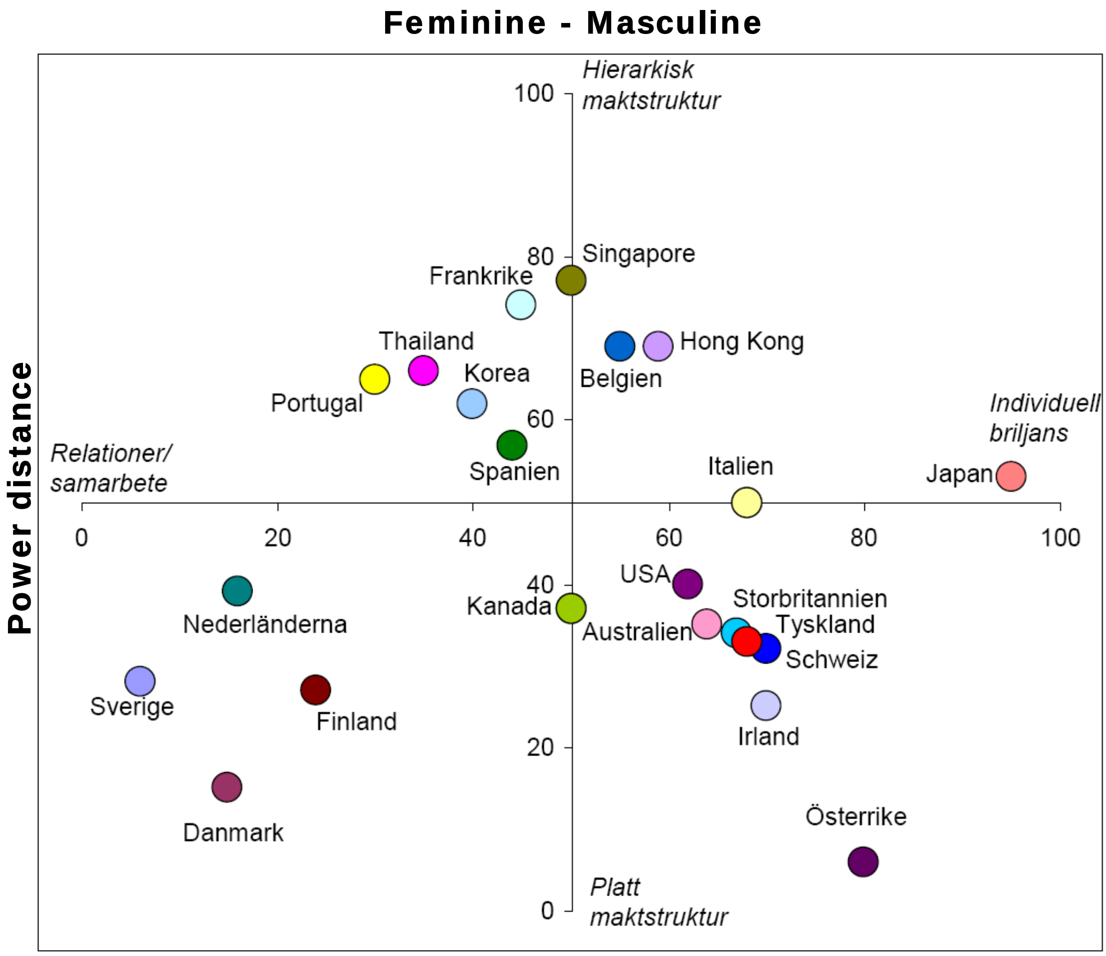


Figure 10: Cultural characteristics of selected countries: Power distance and cooperative vs. individualistic culture (sometimes referred to as 'femine' vs. 'masculine'). Source: Swentec 2007, building on Institute for Intercultural Cooperation (IRIC, Geert Hofstede).[3]

In addition, there is in the Nordic countries a relatively strong tradition for broad engagement in societal issues and societal development. This is also the case concerning the energy area and the energy systems, where there in the Nordic countries are extensive debate and discussions. There is general interest for, and concern about, the challenges and problems in the current systems and an engagement in contributing to solutions and paths of development towards sustainable energy systems. Moreover, there is high awareness about new energy technologies and a relatively strong support in the public for development of renewable energy technologies like solar cells, wind mills, etc. (Eurobarometer 2007, Naturvårdsverket 2006).

	Proportion of population aged 25-64 with higher education (%)		**Proportion of population engaged in life-long learning (%)**	
	2003	2005	2003	2005
Denmark	32,9	33,5	27,6	27,6
Finland	34,2	34,6	24,6	24,8
Iceland	29,2	30,6	31,7	26,6
Norway	32,3	32,6	19,1	19,4
Sweden	28,2	29,2	35,8	34,7
EU-25	21,9	22,8	10,7	11,0

Table 1: Shares of population with higher education and engaged in life-long learning in 2003 and 2005 (RANNIS 2007, building on European Innovation Scoreboard 2006).

[3] Iceland and Norway are not included in the figure, but would appear in the same area as Sweden, Denmark and Finland; with a strong degree of relational and cooperative competences and a relatively flat power structure. For Norway this is documented in another, similar dataset by Geert Hofstede (www.geert-hofstede.com/hofstede_dimensions.php).

In general, a very large number of organisations are active in the energy area in the Nordic countries. And there are many debate meetings and discussion forums where actors communicate and meet across institutional borders. Both professional and non-professional actors are involved; it is not only activities internally within the already well-established part of the energy sector (Koefoed 1999, Tjernshaugen 2007, Borup et.al. 2007). These aspects all contribute to good conditions for thorough and reflective integrations of the needs with the technological potentials.

1.3 Study and report outline

The study behind this report consists in five elements:

1. Characteristics of the Nordic energy innovation systems
2. Analysis of need integration dynamics
3. Patterns of collaboration in R&D programmes
4. Investigation of a row of energy innovation indicators
5. Further policy implications – Final reporting

Of these, 1 and 2 are closely integrated, with gathering and assessment of the knowledge about the Nordic energy innovation systems in general in Element 1, and elaboration concerning need integration in Element 2. The results are presented in Chapter 2 to 6 for the individual countries and with a comparative analysis across the countries in Chapter 7. The work builds primarily on existing studies of energy innovation systems. Only to a limited extent, also other types of written material and personal communication with individual experts are employed. Completely new analyses of the energy innovation systems in the Nordic countries are not within the scope of the project.

Study Element 3 is a quantitative analysis of patterns of collaboration in the public research and development programmes in the energy area in the Nordic countries. More than 1100 projects in the programmes are covered. The full set of results and methodological notes are shown in Appendix A, while the overall main results are presented in the comparative Chapter 7. Selected results are moreover also shown in other chapters, where it was found appropriate.

Study Element 4 is an investigation of a number of possible indicators for Nordic energy innovation. A row of indicators have been identified and, to the extent possible, quantitative figures for the indicators are found. Some of the results are presented already above in Chapter 1.1. Selected figures are referred to throughout the report where it is found appropriate. The full set of indicators and the methodological discussion about the different possible indicators are presented in Appendix B. In addition to figures for the Nordic regions as such, figures for the individual Nordic countries can in many cases also be found in the appendix.

The policy perspectives of the study will mainly be discussed in the comparative Chapter 7 and in the final sum-up of conclusion in Chapter 8. (It has also been touched upon briefly above.) In some cases, additional policy points specifically for the individual country can moreover be found in the single country chapter.

The study focuses on four specific technology areas, all selected from the broader group of technologies that can play an important role in the transition towards sustainable energy systems. The technologies are: 1) bioenergy; 2) hydrogen technology & fuel cells; 3) solar cells; and 4) wind energy. This focus was established in dialogue with Nordic Energy Research. Bioenergy is here delimited to primarily biomass based energy for heat and power. Biofuels for transport is not covered systematically. Where nothing else is noted the term bioenergy refers to bio energy for heat and power while the term biofuels refers to bioenergy for transport purposes. In a few places, also material on other environmentally friendly technologies and renewables are included.

The study is dependent on the coverage of the existing analyses of energy innovation systems in the Nordic countries. This put some limitations on the work. To the extent possible, all five Nordic countries are addressed, however, the amount of existing analytical material is very limited for Iceland. The country chapter about Iceland is therefore shorter than for the other countries and not of the same analytical character. As there are very few activities on bioenergy, solar cells and wind energy in Iceland, observations about geothermal technology are included as well, to the extent possible. There are also relatively few analytical studies of the energy innovation systems in Finland. Among the exceptions are analyses of bioenergy and of hydrogen technology.

The study is one of the so-called 'NORIA policy studies' funded by Nordic Energy Research. The study was carried out by a group of experienced researchers within analysis of innovation systems in the energy area in Nordic countries.

2. Renewable energy innovation systems in Denmark

2. 1 Introduction

The energy innovation system in Denmark has experienced considerable change over the latest decades, resulting in new characteristics of the system on a number of points. Through the 1980s and 1990s, the liberalisation of the energy sector and the opening of markets changed the energy area from a largely publicly controlled and run area to an area with considerable private as well as public activity. The ownership of the energy systems and energy production facilities has become more international and characterised by commercially oriented business actors. It is not to the same extent as earlier characterised by regional or local community-based ownership, though however still a considerable amount of heat and power plants, wind turbines, etc. are owned locally.

Constructions of energy markets are made nationally as well as internationally, e.g., in EU and on Nordic level (Nord Pool) and rule sets for market action and competition are being developed. The regulatory regime of the energy area has changed from an institutional-technocratic oriented regime to a market-oriented regime (Jørgensen 2005).

The energy production in Denmark is mainly based on coal, gas and oil, though the contribution from renewables, primarily wind energy and biomass for power and heat, have increased significantly in the 1990s and the beginning of the 2000s. The actors traditionally connected to fossil fuels: the utility companies, the grid operators, and the oil and gas companies are in general among the influential actors in the energy innovation system.

Through the 1990s and 2000s, the issues of sustainable development and climate problems of the energy sector have become widely acknowledged and are now central on the agenda for the sector's development and a key issue for innovation. This is among other things reflected in the public energy R&D programmes that are focused primarily on environmentally friendly energy technologies and energy efficiency.[4] In general, the R&D spending in Denmark on fossil fuels has since the first half of the 1990s decreased relatively to the spending on environmentally friendly technology. There is considerable dialogue and coordination between the public R&D programmes.

In the recent years there has in Denmark been increasing attention to the energy area as an area of economic and industrial development. The energy area is not only an area supporting other societal activity areas and industry sectors. It is in itself an industrial sector with opportunities for employment, economic growth and development. This view is now well established.

The exports of energy technology and equipment have risen considerably since the mid 1990s and show growth rates larger than the general growth in exports. The exports of energy technology and equipment from Denmark make up more than 50 billion DKK in 2007. This constitutes more than 8% of the total Danish commodity exports (ENS 2008 Export statistics, April 2008). The rise in the exports of energy technology and equipment means that this type of exports is no longer minor, but comparable, to the considerable oil and gas exports. The societal importance is accordingly high. To some extent, the innovation-oriented regime is challenging the existing market-oriented regime. The share of renewable technologies' contribution to the export has risen from around one fourth in the 1990s to around 70% in 2004. Wind technology accounts for most of this.

[4] The R&D programmes are the The Energy Technology Development and Demonstration Programme (EUDP) intended to replace the Energy Research Programme (EFP) managed by the Danish Energy Authority; the PSO programmes (Public Service Obligation) managed by the grid responsible organisation (energinet.dk) and the energy companies; and finally, the energy and environment programme of the Research Council for Strategic Research.

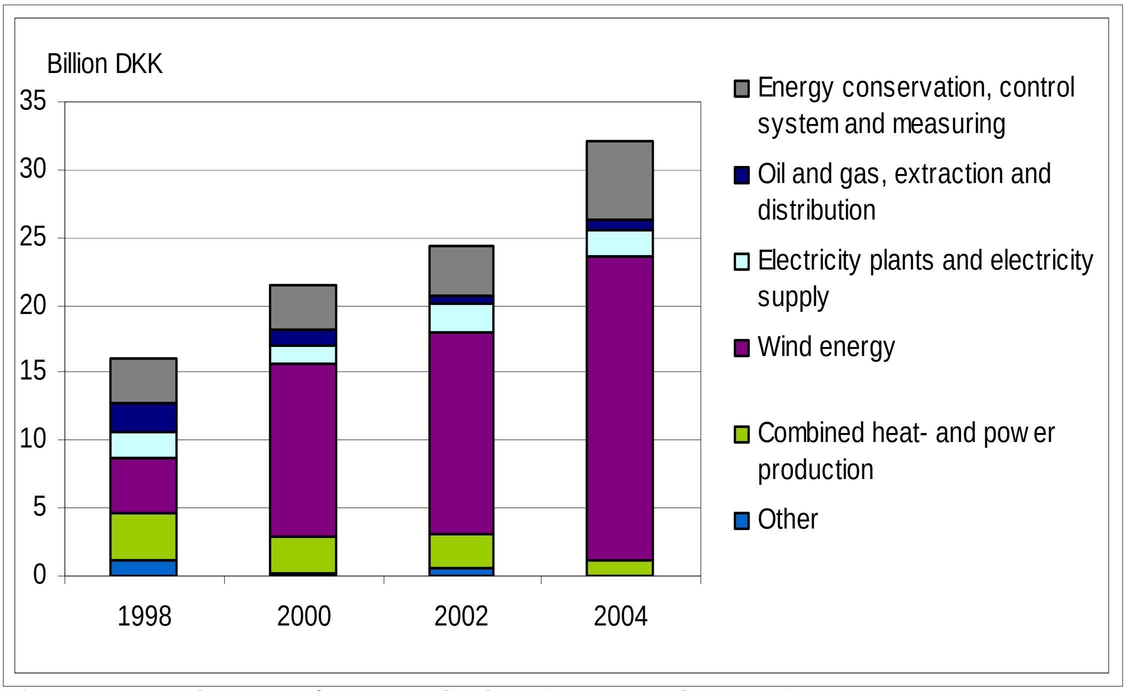


Figure 11: Danish export of energy technology (Energistyrelsen 2006).

The Danish energy innovation system reflects the general industry structure in Denmark with many small and medium sized companies and relatively few large companies. The long tradition for interrelation with the agricultural sector is often clearly reflected and of significant influence to the characteristics of the innovation system. This both appears directly, for example, in the bio energy area where agricultural waste material is used in the energy production, and indirectly on cultural and organisational level where the traditions for co-operatives and communities-based organisation are significant.

There is in general a broad engagement and extensive public debate and discussion about the energy area and the energy systems (Federspiel 2002). There are a vast amount of debate meetings and discussion forums where actors communicate and meet across institutional borders. In general, a very large number of organisations are active in the energy area. Both professional and non-professional actors are involved; it is not only activities internally within the already well-established part of the energy sector (Koefoed 1999, Borup et.al. 2007). Moreover, there is high awareness about new energy technologies and a relatively strong support in the public for development of renewable energy technologies like solar cells, wind mills, etc. (Eurobarometer 2007).

National strategies for research and development within a limited number of energy technology areas are defined. The technology areas below, bio energy, solar cells, wind energy, hydrogen technology and fuel cells are all among the prioritised areas selected for strategies. In the bio energy area both a strategy for bioenergy in heat and power production and a strategy for bio fuels for transport exist. The innovation systems with respect to individual areas of energy technology vary considerably and are quite diverse.

2.2 Wind energy

Actors

The successful development of wind power technology in Denmark in the latest decades is now relatively well-known. The wind power innovation system consists in a very broad range of actors, stretching from engaged citizens and small investors, over industrial sub-suppliers, consultants, public authorities and NGOs, to large international companies, policy makers, and industry associations. The area counts, estimated, in the order of 300 organisations, centred around three large companies: Vestas Wind Systems and Siemens Wind Power which are two of the worlds' largest manufacturers of windmills; and LM Glasfiber, which is the largest supplier of blades.

The Danish wind industry has a share of around 1/3 of the world market for windmills. Wind technology has obtained the role as one of the largest export areas in general for Denmark with exports in 2007 of value 4,7 billion euros. Around 23.500 people are employed in the area (DWIA 2008).

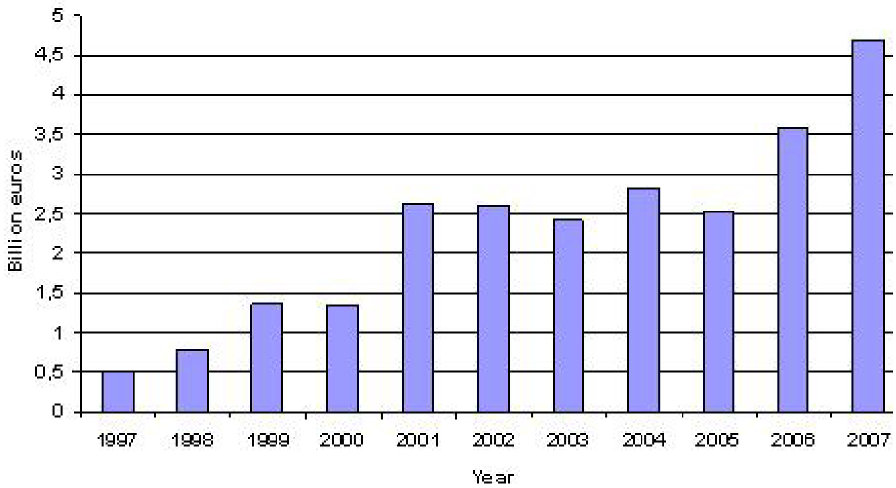


Figure 12: Annual exports of wind turbines, components and services from the Danish wind energy industry (source: Danish Wind Industry Association 2008).

Another important group of actors are the private owners of windmills, locally, primarily in rural areas. The owners are usually either individual farmers or groups of citizens that organize in local co-operatives in order to establish windmills locally. The connection to agriculture and traditional organisational forms in the agricultural area is close.

The central energy companies are not main driving factors for innovation of Danish wind technology. For many years the energy companies were reluctant or in opposition to windmills as it did not fit easily in the regime of coal and high-efficient heat & power plants. When energy companies today are active players as owners and developers of wind plants it is primarily due to national policy. Government and national policy makers have strongly supported the wind energy development and forced the energy companies in this direction.

Patterns of need integration and learning

The wind energy area in Denmark is today a relatively well-established area. It is mature with respect to industrial networks as well as to application and integration in the energy systems.

The innovative learning in the wind area to a large degree occurs through practical application of windmills. Experience is gathered in dialogue with owners and operators of windmills and wind parks. The products are more often gradually improved than completely redesigned. Important innovative learning moreover appears in the well-developed supply chains between the manufacturers of windmills and the multitude of sub-suppliers. Learning-by-using and learning-by-doing is thus a central element of the learning patterns and of the integration between technological opportunities and needs in practice in the area.

A strong domestic market established in the late 1980s and the 1990s constitutes a basis for this. It has made it possible to carry out large scale experimentation with real application. The application is widespread. Wind power has in the latest years made up 16-19% of the total electricity production. The experience gathered through the widespread application is considerable, also concerning knowledge about integration in the electricity grids and the operation of wind power plants together with other types of electricity production. No other country has a similar large share of wind energy in the electricity system.

After the change to a liberal-conservative Government in 2001, the development in the strategic domestic market stopped. Few new installations are made in the latest years. The stagnation in the domestic market has limited the opportunities for experimental applications of new solutions. Offshore wind plants, which are one of the newer types of wind plants where more experience gathering is of strategic importance, is to some extent an exception, but the activities have slowed down significantly.

The strategy of competence building through application and learning-by-doing in the Danish innovation system has been compared to strategy for knowledge and competence e.g. in United States. Here an approach of more abstract, science-based modelling with roots in aircraft design and aerodynamics was chosen. One of the explanations of that the Danish approach turned out to lead to more viable windmills is that there in the approach in US was little cross-functional communication between engineers and the skilled workers and operators with the practical experience about the windmills (Karnøe 1996).

The large network of sub-suppliers constitutes a complex and expanding knowledge-base (Andersen & Drejer 2006). Many of the sub-suppliers are small and medium sized companies from the machine and metal industries. These types of companies have been of strong importance for the wind innovation, also in the early developments in the 1970s and 80s. Considerable positive external economy and build-up of new businesses and competence areas have occurred. Apart from specialised suppliers of components the business actors are e.g. consultancy companies, service providers, providers of simulation and control systems, investors and developers of wind farms.

The Danish wind innovation system has character of a strong industrial cluster with considerable synergies between the many activities and the complex networks. A number of foreign windmill manufactures have established development units in Denmark in order to hook on the qualified learning.

The wind industry has experienced a concentration on fewer manufacturers and an increased internationalisation. Large multinational conglomerates appear more often (like Siemens and General Electric) and the Danish manufacturers have established production subsidiaries in a number of countries around the world.

Despite the large export markets, globalisation tendencies and the internationalisation of the manufacturers, the innovation system is to a significant extent embedded in and tied to the local, national context. This shows for example in analyses of the collaboration patterns and networks between the actors where the domestic contacts are more frequent than the international, see figure 13. (Of the four energy technologies in focus in this report, wind energy is in Denmark clearly the most internationally oriented area. Even here, the only exception to the general picture of domestic cooperation as most important is in the category collaboration with parent companies and subsidiaries).

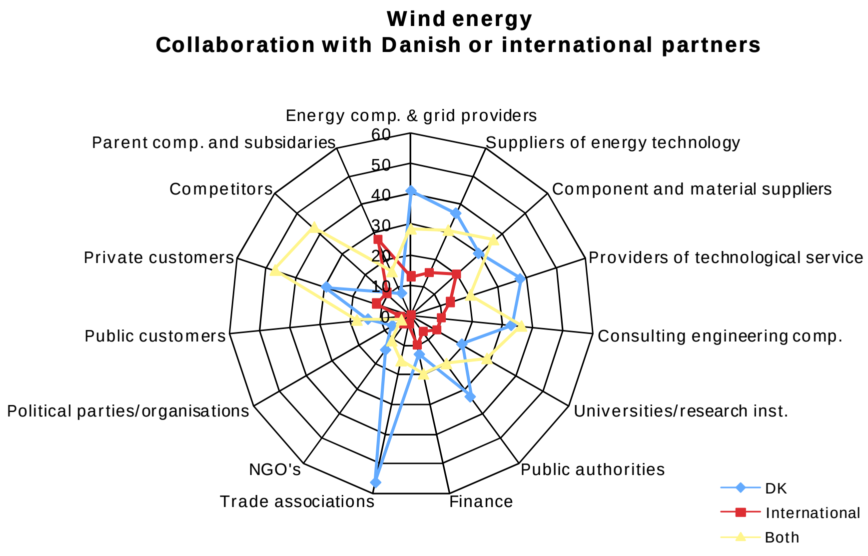


Figure 13: Domestic and international collaboration partners for actors in the Danish wind energy innovation system (Borup et.al. 2007).

There are extensive debate and public discussion in Denmark in the wind energy area. The integration of needs in technological innovation activities also occurs through these dynamics and they are important for the learning. They guide the direction of innovation and contribute to legitimation.

The many engaged actors in the local, cooperative ownerships and in energy NGOs are important for this. In recent years, strong and renewed media attention has occurred, not least in connection with the two overall issues climate problems and business development. Moreover, a considerable amount of interest organisations, professional as well as citizens-oriented, have appeared: Not only associations like the wind industry association and associations of windmills owners, but also e.g. association for windmill assurance, association of neighbours to windmills, to mention just a few. To this comes establishment of subgroups within a number of existing interest organisations for example in energy in general and in general industry associations.

Many of the interest organisations are not just in a narrow sense arguing for their interest but act as disseminators of information. It has been pointed out that the fact that the actors in the Danish wind innovation system have succeeded in establishing a framework for open dialogue and information dissemination, despite the strong degree of industrialisation in larger and larger companies, is of significant importance for the development in the area (Koefoed 1999w).

Research institutions (primarily Risø National Laboratory and its 'Test station for wind turbines', now the Wind Energy Department), are among the institutions that have actively pursued this strategy. They create an arena for communication and information exchange and feed in results from their own research in the arena. Moreover, the research institutions have been active in establishing test and certification systems for windmills in collaboration with the energy authorities.

There has been considerable national funding for research and development in wind energy over the years. That the wind technology is applied widely does not mean that research does no longer play a role. On the contrary, of the four technology areas in focus in this study, wind energy is the area where research actors are involved in the largest proportion of the projects in the national R&D programmes. The area is further characterised by relatively many collaboration projects between research institutions and private companies. Education on wind energy was more or less absent for a long time, but in recent years this has changed and a number of universities (and Risø) are now active in the field. The wind manufacturers moreover have established collaboration with educational institutions in Denmark as well as abroad.

Public policy and regulation are as mentioned central for the innovation in the wind area in Denmark. Need integration through regulation is thus also important in the learning dynamics. Wind energy is high on the agenda in general and prioritised in the energy policy. Tariff support is established. It has been very important in periods but is smaller now than earlier. A row of different policy measures have been employed, ranging from planning legislation, grid legislation, over tariff support and green taxes, to support of research and development. Moreover, systems for type approval, certification and for operation and maintenance are defined. The regulation is characterised by an attempt to coordinate policy efforts in a strategic way. Economical measures are combined with other means.

Resulting picture

The wind energy innovation system is a mature area with respect to industrial networks and as integrated part of the energy systems. The developments in wind technology have lead to significant change in the electricity systems and the fossil fuel regime has been challenged. In addition considerable economic development and a strong industrial cluster are created.

Significant synergies between the many different kinds of activities in the innovation system have appeared. The patterns of innovation is characterised by considerable dialogue and interaction among many different types of actors. Learning-by-doing, learning-by-broad-discussion, as well as learning-through-regulation are all important for the innovation in the wind energy area.

2.3 Bioenergy

Actors

Bioenergy in Denmark primarily means production of heat and electricity. The bio energy innovation system is closely connected to the traditional actors of the energy area: the power plant companies, Government, and the public authorities. Development activities, experiments and demonstration projects to a large degree take place in connection to the existing power plant companies and their facilities. Bioenergy constitutes the largest area of renewable energy, around 11% of the total energy supply, and it has grown considerably through the 1980s, the 1990s and the 2000s. The growth rates in the energy production are in average in the 2000s more than 7% a year.

The development is primarily driven by national policy for more renewable energy and less fossil fuel in the energy systems and, more specifically, for use of agricultural residual products and waste in the energy systems. This means that the bioenergy innovation system on central points is integrated with the agricultural sector and the waste-handling area. The policy can be seen as a case of industrial ecology on the macro scale level of sectors. The policy has in the latest years reduced the degree of detailed planning and followed a more liberalisation-oriented direction. Local energy companies, communities, and farmers have had a significant influence in the innovation in bioenergy area (Raven 2005, Koefoed 1999b). Their role have however decreased in the last 10-15 years, where the growth in bioenergy has primarily taken place in the central power plants, not in the decentral plants.

Apart from the energy companies themselves, the industry consists in suppliers of heat & power plants and suppliers of smaller or larger plant components, e.g., central components like turbines and boilers. To some suppliers, bioenergy technology constitutes only as small part of their products, while others have it as main field of activity (Skytte et.al. 2004). A considerable number of Danish suppliers exist. Some are smaller companies from the machine industry; others are subsidiary companies of larger, international companies. In addition there are a number consultancy companies and 'technological services institutes' (semi-public) with expertise in power plant technology, combustion, etc.

Patterns of need integration and learning

With national policy as the main driving force for innovation in the bioenergy area, the articulation of needs and requirements for new technology appear through the national plans and regulation of the energy area. Overall goals as well as specific targets for use of e.g. straw, wood and other types of biomaterial in power plants have been defined through a number of successive agreements in parliament and between the Government and the actors of the energy sectors. Recently, in the Parliament's energy agreement primo 2008. It implies an increase in use of biomass on 700.000 tonnes/year by 2011 which will increase the renewable energy share by 1,2 percent points. Earlier, for example in the 'Biomass Agreement' from 1993 which established that the large, central power plants before year 2000 should use at least 1,2 million tonnes straw per year and 0,2 million tonnes wood chips.

The energy companies have taken up the challenges in a learning-by-doing manner by increasing the use of biomass in existing power plants and by establishment of new full-scale plants for biomass. As supplement to this, and building on the experiences gathered from the practical use, a number of more experimental plants, development programmes and research activities are established. The learning thus takes place primarily in the energy companies and between them and their collaboration partners. This among other things means that the existing knowledge about combined heat & power, district heating, etc. to a considerable degree is integrated in the learning about biomass technology.

The development activities have followed a number of different technology tracks. No dominating design is established. Different types of biomass have very different combustion characteristics and the challenges and practical problems e.g. concerning efficiency, corrosion, and residual components vary considerably. Within combustion both grate-fired systems, fluid-bed systems, suspension-fired and dust-fired systems (co-firing) are investigated. Experimentation with gasification systems (fluid-bed and fixed-bed) and with 'Stirling machines' is carried out. The smaller area of biogas (from manure etc. and closely integrated with agricultural area) has also undergone important technology developments.

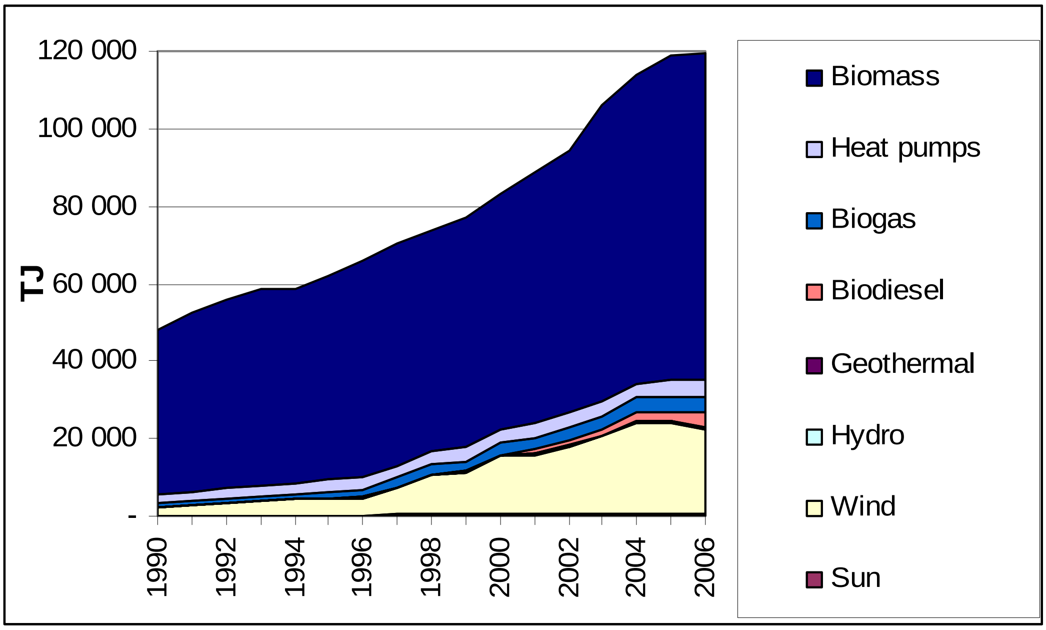


Figure 14: Renewable energy production in Denmark in TJ. Source: Danish Energy Authority. Data downloaded from http://www.ens.dk/sw11654.asp.

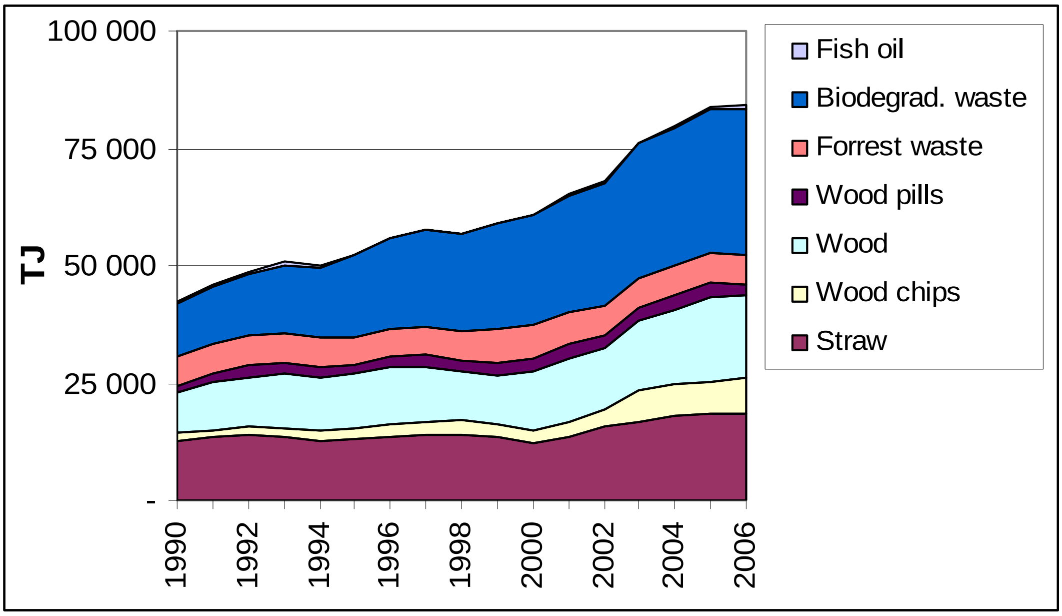


Figure 15: Detailed distribution of the biomass component in Figure 14. Source: Danish Energy Authority. Data downloaded from http://www.ens.dk/sw11654.asp.

In general it is considered that Denmark is among the leading countries on bioenergy technology and on practical design and operation biomass systems. Actors indicate that specific strength areas e.g. are combustion of straw and other grass fuels, the use of waste in grate-fired plants, and gasification in de-central heat & power plants.

The policy and regulation employ economical measures as part of the policy plans. There is price subsidy for the electricity produced. The subsidy compensates for the obligation to use biomass resources and is given after complex rules depending on among other things fuel types, plant size, and date of establishment. Moreover, the environmentally oriented tax system gives renewable bioenergy a relative advantage compared to fossil fuels (IEA 2006, Energistyrelsen 2005a).

In practice, the support of market formation has not been as strong and as clear an incentive for innovation as it has been seen in other areas. One reason is the favouring of another energy source, gas, for decentral power plants. This has to some extent hampered the opportunities for a market for biomass technology in decentral power plants.

Another reason is that there with the combination of heat and power production and with the integration with agricultural production, with waste handling, etc. are many different ‘product areas’ involved in bioenergy plants and it is difficult to establish a clear market dynamic and clear market signals. This is further complicated by the many different biomass sources and the variation in mix of fuels in the different power plants. For many of the types of biomass that are important in the Danish system (straw, livestock residual products and household and industrial waste) there are moreover no well-established international markets to integrate with.

All together, this means that rather than one market for more or less standardised products, the establishment of biomass fuelled plants have character of a number of individual solutions tied to the specific context. The limited market formation for the biomass technology has implied that a number of suppliers of technology and equipment left the area, as there was not basis for permanent presence.

Exports of bioenergy technology have been relatively low and disappointing to the actors, in light of the considerable development in the domestic market and the considerable build up of knowledge and experience. While bioenergy in the mid-1990s was the second largest export area within renewable technology (Koefoed 1999b), the exports decrease in the years around 2000 from 700 million DKK to estimated 300 million DKK. The decrease is not least due to decrease within combined heat & power systems (VHF 1999, ENS 2000 and 2006). The newest statistics on exports of energy technology do not show bioenergy separately, but there are signs from a number of industrial companies as well as energy companies and research actors that the picture is changing again. For example, a number of bioenergy power plants are to be delivered to the German market, each of value around 100 million DKK.

Part of the reason for the disappointed export expectations is probably the close ties to the Danish context and the fact that many foreign markets and energy systems differ considerably from the Danish, for example by only having little district heating or with respect to the types of bio materials available.

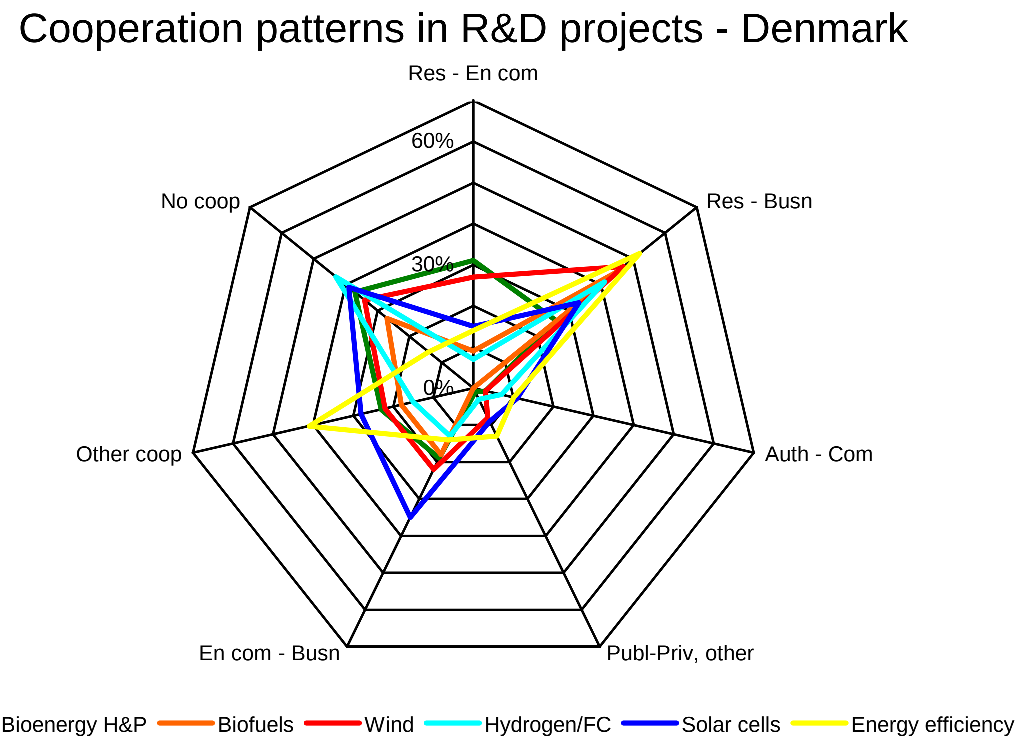
Bioenergy is one of the technology areas that receive the largest amount of funding from the national research and innovation programmes. The general pattern of the innovation system with respect to bioenergy is reflected in the programmes’ projects and the actors involved. Compared to other technology areas there is a relatively large share of projects with participation of energy companies, (44%, compared to 33% in average). Other industrial and business companies are less often involved, only in 38% of the projects (compared to 64% in average for all technology areas).

Table 2: Denmark – Actors in national R&D programmes (number of projects).

	Energy companies	Business companies (other)	Research	Authorities	TSI	Other	Total N
Bioenergy - H&P	44%	38%	69%	5%	27%	3%	150
Biofuel – transport	18%	64%	82%	0	9%	0	11
Wind energy	38%	59%	80%	5%	19%	9%	64
Hydrogen & fuel cells	16%	72%	63%	7%	13%	4%	68
Solar cells	37%	85%	39%	11%	20%	13%	46
Energy efficiency	27%	82%	67%	10%	37%	16%	153
Total	33%	64%	66%	7%	26%	9%	492

Source: DENP database (Danish Energy R&D projects). Running projects 2007, plus new projects accessed medio 2008. The database covers all projects within the relevant programmes: PSO, EFP and ENMI. Own account building on the database and supplemented with project information and information material about organisations.

More than 30% of the projects are cooperation projects between energy companies and research institutions (see Figure 16 and Appendix A). Bioenergy is the only technology area where cooperation between research and energy companies is more frequent than between research and industrial companies. Actors from a number of scientific fields are involved in the bioenergy developments. Among the largest areas are combustion engineering and machine engineering. Fields like advanced biotechnology research and material science are becoming increasingly important.



How to read these spidernet figures:
The figures show share of projects in the energy R&D programmes with cooperation across different types of actors. The types of actors are: Energy companies (En Com) and Other companies (business, industrial, service, etc.) (Busn). Together they make up the category Companies (Com). Moreover: Research institutions (Res), Public authorities (Auth) and 'Other actors' including e.g. interest organisations and NGOs. Authorities and research are accounted as public organisations while companies and interest organisations are accounted as private organisations.

'Res – En Com' thus shows share of projects with cooperation between research institutions and energy companies, while 'Publ-Priv, other' shows share of projects with other kinds of cooperation between public and private organisations than already mentioned, i.e. than 'Res - En Com', 'Res – Busn' and 'Auth – Com'. This could for example be projects with cooperation between research institutions and interest organisations. See details in Appendix A.

Until recently biofuels for transport was not a prioritised area in Denmark. Within the last couple of years this has changed due to EU requirements of use of biofuels in the transport area, with large funding for demonstration and development projects as one of the results. The strategy is to develop so-called 2nd generation technologies i.e. biofuel produced from waste and residual products rather than food crops.

From above it can be seen that two of the three overall types of integration of needs with technological opportunities play an important role in the bioenergy area: 1) integration through regulation and 2) learning-by-doing / learning by using. Integration through discussion and debate is also important, not least when it comes to discussions in professional networks and in the numerous interest organisations there exist in the area. There is also considerable interest from a broader number of actors than the above mentioned, including NGOs, local communities, and citizens in the broader public (Koefoed 1999). The public discussion and engagement is however relatively smaller, compared to areas like wind and solar cells.

In the broad discussions about bioenergy focus is on CO2 reductions, while there is little attention to other environmental emissions such as NOx, tar and ashes with heavy metals. Though there are activities addressing the opportunities for reductions of these emission types, the interaction for integrating technological opportunities and these needs is weaker than the interaction concerning CO2 reduction and renewable use in general.

Resulting picture

To sum up, the innovation system in the bioenergy area is embedded in the conventional energy system in Denmark with the traditional energy companies as the central actors and close connections to agriculture and to the waste sector. The national policy is the main driver for the developments. Considerable knowledge build-up and technology innovation take place and significant changes are made in the Danish energy systems.

There are limitations in the market formation and in the creation of positive external economy, apart from in and around the existing energy companies. New business areas viable on market-basis and on foreign markets have only to a limited extent been built up so far, but are to some degree expected to appear in the future.

2.4 Solar cells

Actors

The innovation system with respect to solar cells in Denmark is relatively small. It is estimated that there are around 20-30 organisations and in the order of 200 persons[5] working in the field (depending on how broadly you count). Of companies, there are a limited number of retailers and suppliers of solar cell systems, for the domestic market primarily. Moreover, there are a handful of industrial component suppliers that produce e.g. system integration components, power electronics, and semiconductor material, primarily for foreign markets. Also stand alone systems like e.g. solar driven pump systems are produced.[6]

A number of consultants within engineering and architecture appear in the field as do a number of energy NGOs. Apart from advising, the NGOs carry out more general information dissemination and discussion activities (Ahm et.al. 2006). For the energy companies in general, solar cells are not a prioritised area. A few of them, especially EnergiMidt, have however been steadily engaged in the field. A few research institutions and a technology institute appear. The latter runs a test and certifying institution for solar cells. Research is done on among other things power electronics, architectural integration and new cell materials of the PEC type (photo-electro chemical) and of polymers.

A ‘dialogue group’ and network of actors established by the Energy Authority with many of the above have been important for the activities since solar cells in the beginning of the 1990s was included in the research and development strategy for solar energy in Denmark.[7] Compared to other areas of energy technology, there are not many interest organisations established specifically on solar cells. A branch organisation was established recently, though.

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[5] IEA PVPS 2005: PV-Trends 2005, here referred from Ahm et.al. 2006.

[6] Grid connected systems are normal in Denmark. However also off-grid systems for example for farming purposes, signal systems, leisure boats etc. appear.

[7] Before 1992 solar energy primarily meant energy for heat and warm water. Now it is opposite: Heat and warm water have disappeared from the national strategy plans for research and development in energy. Solar cells are the only solar technology considered.

Patterns of needs integration and learning

The solar cell innovation system can be said to fall in three parts:

1) the component manufacturers working in niches on the international market;
2) the research in new cell materials; and
3) the domestic demonstration and application oriented activities.

The synergies between the three parts are limited. The innovation system is in this sense, and with the relatively few actors, not a fully mature innovation system.

The component production has in recent years been driven by the policy-created boom in the markets abroad, especially in Germany and Japan. Since 2000, the supply chain networks have developed fast. Considerable learning both concerning the components and the production of them has appeared through the learning-by-doing in the changing supply chain networks. For the Danish companies who managed to establish niche roles on power electronics, high-quality silicon material etc., exports have risen considerably the latest years, from almost nothing, 0,01 billion DKK, in 2001 to 0,2 billion DKK in 2006.[8]

The large economical policy support has however also resulted in bottleneck problems and price increases on silicon material and solar cell systems as such (Ahm et.al. 2006). The raw material bottleneck has for the Danish manufacturer implied a halt in production apart from a small production for research purposes. In addition to the learning-by-doing in the supply chain networks, the learning for the component manufacturers in some cases also takes place through connections to scientific research.

The domestic application of solar cells in Denmark is until now little and installation of new effect is scattered and slow. A limited number of households, residential buildings and public and private business buildings have solar cells. Learning from domestic application has taken place in a row of development programmes in the 1990s and early 2000s focused on actual implementation in a certain amount of buildings with a larger or smaller degree of investment subsidy, depending on the degree of experimental character of the installation. At present there are no programmes that similarly can ensure strategic learning from application and application-oriented experiments (Ahm et.al. 2006).

A number of research and knowledge areas appeared in connection to the earlier programmes, e.g. research on system design, modules, inverters, building integration and architecture. In parallel to the application activities more specific research projects were carried out. Moreover demonstration and information activity for the broader public was done. Apart from local, community-based energy companies, also local municipalities and urban development institutions have in some instances been engaged (Copenhagen and Herning).

The research in new cell materials is taking place at the research institutions primarily. There are not (yet) close connections to industrial production or application in practice. The solar cell area is characterised by a relatively low share of collaboration projects between research institutions and companies in the national R&D programmes (33% of the projects, compared to, e.g., 56% within wind technology and energy efficiency). In general, the funded projects often have industry participation (85% of the projects) while there are relatively few projects with research participation (only 39%, compared to between 63% and 82% in other energy technology areas). The funding for research and development in solar cells is in general low and varying considerably from year to year.

There is large goodwill and support of solar energy in the public. The support is the largest in the EU countries, with 95% of the population in favour and little ignorance (Eurobarometer 2007). Though a minority of people have solar cell systems, there is relatively much attention to them. Solar cells often appear as symbol of environment-friendly living and of the need for taking action for reducing the climate problems. It is an icon of sustainability values. The information and debate activities by energy NGOs and information institutions are important in this connection.

The general focus in the media and public discussion about climate problems and the need for sustainable energy system must be considered a main reason for that scientists e.g. within material physics and

[8] Source: Energi Industrien 2006 (see Ingeniøren, August 25, 2006, cf. Ahm et.al. 2006, p. 28.)

nanotechnology in a number of cases ‘suddenly’ have started to develop visions about their knowledge as something that can lead to improved solar cells. The visions are guiding the research activities.

Apart from the R&D funding there is in practice little policy support and innovation-oriented regulation efforts. A net account system where owners of grid-connected household installations only pay tax for their net consumption of electricity from the grid, has only recently been established permanently – more than 10 years after the first grid connected installations. For larger installations, a feed-in tariff system ensures a minimum price for the produced electricity. This is however of little practical importance as the tariff is too small to make a significant difference in the economy of the installations. All in all, the need integration and innovative drive through support of market formation are currently very limited and stand completely in the shadow of the efforts in Germany and other countries.

The recently renewed general building code increases the requirements to the energy performance of new buildings. This has led to new innovative activities by architects, including integration of solar cells.

Economic reasons are not the prim argument when decisions to install solar cell systems are made. Usually the main reasons, for example in connection with new office buildings, are in addition to fulfilling the building code, the environmental advantages, the values signalled and the prestige it can give. Similarly, some energy companies support solar cells in order to show climate awareness and be able to offer the opportunity to interested customers. EnergiMidt hence offers investment support, however to a very limited number of installations a year.

Resulting picture

The solar cell area in Denmark is as innovation system small and scattered. Innovation activities are taking place in a number of individual niches. They do not together constitute a full, mature innovation system. Solar cells have in the recent years been taken up by architects and within architectural education. Integration more broadly in the building and construction industry is still lacking. In general there is a lack of education on solar cell issues.

Though there is considerable public attention to solar cells and they have status as a symbol of environmentally friendly living, there are not many strong actor groups supporting them 100%. With the decentral character, solar cells are not in line with development strategies of the large energy companies focused on central heat and power.

The policy in the field appears half-hearted and somehow odd. The strategic edge of the policy efforts and regulation could be improved considerably. This could for example be done with focus on the specific application context in the local building style and building sector.

The market formation is weak. The use of marked-based policy measures is little. Stronger focus on specific niche areas and learning in specific domestic use contexts would be fruitful. With fast growing application abroad and rising prices on solar cells, extraordinary learning and added value are not created by just relatively small feed-in tariffs on mainstream electricity market. There is no innovation perspective in only being a small follower on the large mainstream markets.

The current national funding programmes for energy R&D do primarily support individual technical and scientific projects. Broader projects for establishment of niches of advanced and specialised applications and leading niche markets do not seem possible within the current programme structure.

2.5 Hydrogen and fuel cells

Actors

Like solar cells, the area of hydrogen and fuel cells is small and relatively immature. It is estimated that there are in the order of 20 actors in the innovation system. Among the leading actors on fuel cells are two of the large technical research institutions in collaboration with a small number of dedicated and research-oriented companies, e.g., IRD, Haldor Topsoe (Topsoe Fuel Cell), and Dantherm. On hydrogen, a number of regional authorities and innovation-supporting institutions play a significant role. The regions are for example Vestjylland (Ringkøbing, Herning), Nordjylland (Hobro), and Lolland (Nakskov).

A high prioritisation by national Government and the Energy Authority has been of central importance to the hydrogen and fuel cell developments in Denmark. Interest organisations, primarily branch organisations, but earlier also more popular based energy NGOs, have been active in the field. Energy companies are not the main leading actors driving hydrogen and fuel cell innovation, however some have been active or made investments in the field. Moreover, concerning hydrogen as fuel in the transport sector, petroleum suppliers appear in some instances.

Patterns of need integration and learning

Innovation activities in the area of hydrogen and fuel cells is closely related to the public funding through national research and development programmes and, moreover, through regionally oriented innovation support. Hydrogen and fuel cells were established on the agenda for Danish energy research and innovation in the late 1990s. Since then national R&D strategies have been defined both for hydrogen and for fuel cells (Energistyrelsen 2003 and 2005b). There is considerable overlap in contents and in actors involved. Hydrogen and fuel cells have in the recent years been among the prioritised technology areas for energy research and development. It is one of the areas that receive the largest amount of public programme funding: in the order of 50-100 million DKK a year (and expectations of 150-200 million a year until 2015). Most of the funding goes to fuel cells (Energinet.dk 2007, Jørgensen 2003, Borup et.al. 2007).

In 2006 a national 'public-private partnership' for hydrogen and fuel cells was established, as a new institution form in the national management of research and development in the energy area. The purpose of the partnership is to be a platform for cooperation, information exchange and strategic coordination of the hydrogen and fuel cells activities. Through this, technology development, commercialisation and application shall be supported. The partnership has participation by most of the actors in the innovation system including industry, research and national authorities. The Danish Energy Industry Federation acts as secretariat. A large part of the strategy development and strategic discussion happens within the partnership.

On hydrogen, the innovation activities to a large extent consist in demonstration projects. They aim at showing the potentials of the hydrogen technology, often by establishing small, experimental application examples, e.g., small vehicles for hospitals, parks or airports or heat & power systems for a small group of single-family houses. Actual application outside the demonstration projects does almost not exist. In many cases the demonstration activities are carried out in collaboration between regional authorities and industry companies. In addition to demonstration projects, a number of projects on issues like hydrogen storage, distribution systems and safety take place.

On fuel cells, the innovation activities primarily consist in advanced material research, electrochemical surface technology, and control and steering techniques. There are considerable challenges in creating robustness and durability of the cells and in improving efficiency and reducing the costs. Two types of fuel cells, PEM (Proton Exchange Membrane) and SOFC (Solid Oxid Fuel Cells) are developed by collaboration coalitions between industry companies and research institutions.

Like for hydrogen technology, actual application of fuel cells is currently very little apart from in demonstration projects like mentioned above. Production facilities for fuel cells are established, however still primarily as pilot production and production for research and experimental purposes. Some experience about production, sub-supplier networks etc. is built-up, but considerably more is needed if actual market application should be established.

Many of the actors in the hydrogen and fuel cell area participate in international activities and projects, e.g. EU research projects and Nordic projects e.g. the Scandinavian Hydrogen Highway Partnership. Topsoe Fuel Cell and Finnish Wärtsilä have a strategic partnership on fuel cells systems for distributed generation and auxiliary power units for marine applications.

Educational activities are established in the shape of a Ph.D. school and courses in master curricula primarily at the technical universities. Moreover, hydrogen and fuel cells appear as case area for students for example at business schools.

Comprehensive 'road maps' with long-term time plans and performance targets are defined for each of the two types of fuel cells in the national strategy. This facilitates a degree of competition between the cell types and a possibility for comparing with international developments. The road maps are however confidential information for commercialisation reasons. This inhibits a broader discussion about the progress and perspectives of the R&D activities. In general there is very little public discussion about the fuel cell technology.

Compared to fuel cells, there has on hydrogen been some degree of broader discussion, especially in the first part of the decade where a number of foresight processes and strategic discussions on regional and national level were carried out (e.g. Ringkjøbing Amt 2003, Hobro Kommune et.al. 2006, IDA 2003, Dannemand Andersen et.al. 2005). The broader discussion and interest are in general more limited in extent than e.g. in wind energy and solar energy.

Moreover, there often are important gaps in the communication e.g. in the media. For example there is almost no discussion about the energy efficiency of hydrogen. The fact that hydrogen is not in itself a sustainable energy source but an energy carrier is often 'forgotten'. The environmental and climate aspects are hence usually treated on a very general level only or left out of consideration. Similarly, the fact that fuel cells can be driven by many other fuels than hydrogen, e.g. methane, and what the different alternatives imply with respect to energy systems, infrastructure, sustainability impacts, knowledge needs, etc., are rarely discussed. All in all, needs integration through broad discussion only occur to a small extent in the hydrogen and fuel cell area.

Resulting picture

There is in the hydrogen and fuel cells area a strong inner tension between the broad and large visions and the very limited application in more or less artificial and protected settings, far from ordinary market use. Most striking this maybe appears in the contradictions between the far-reaching, general visions about 'hydrogen society', hydrogen-based transport infrastructure as alternative to the current oil-based regime, etc., and demonstration projects with e.g. one small service vehicle for hospital or airport use.

It can be concluded that the area of hydrogen and fuel cells to a large extent is a 'technology push' area more than a 'demand pull' area. The need integration processes are weak as there is in general relatively low degree of interaction between the application side and the research/development side.

This is confirmed by the analysis of cooperation patterns in the energy programmes. It shows that there in the hydrogen and fuel cells area is a relatively large share of project with no cooperation between different types of actors (43% compared to 30% in average for all technologies). 41% of the projects involve cooperation between research institutions and industrial companies. Only 7% have cooperation between research institutions and energy companies, reflecting the relatively low participation by energy companies in general in the area.

Apart from funding in the national research and development programmes, there are no national policy efforts and regulation in the hydrogen and fuel cells area. Learning and need integration through public regulation and demand hence play only a very small role. Recently, though, a tax reduction for cars driven by hydrogen or electricity instead of petrol was decided upon.

2.6 Concluding reflections - Danish energy innovation systems

The innovation systems of the individual energy technologies in Denmark are quite diverse and the maturity of the technology areas with respect to application and industrial networks vary considerably. Bio energy and wind energy are relatively mature, hydrogen technology and fuel cells are immature, and solar cells are somewhere in between. The differences consist in among other things the actor set-up, the industrial structure and the degree of embedment in the existing energy systems and existing energy companies.

Bioenergy is closely related to the existing energy companies and the mainstream energy systems. Innovation in wind energy appeared as alternative to the mainstream systems but is now fully accepted and integrated. Solar cells are a small niche of little importance currently and hydrogen and fuel cells appear as an innovation area to some degree disconnected from the general energy systems.

Usually the technology innovation systems are significantly shaped by competences and practices in areas other than the energy area. For example, wind energy and bio energy build on competence bases of the machine industry and the agricultural sector and hydrogen/fuel cells builds on a.o.t. electro-chemical industry and research.

Learning-by-doing and learning-through-discussion in combination with advanced knowledge production is a characteristic feature of the Danish energy innovation system.

The analysis shows that despite internationalisation, the energy innovation system belongs to primarily the national level. The connections to the local environment (industry, knowledge networks, energy systems and policies) are very important. Most of the complex interactions and networks that make up the innovation systems are within the individual country; not across the borders. The embedment of energy innovation systems on the national level can for example be seen from the spider-net figures in appendix that show the amount of domestic and international collaboration for actors in the different technology areas. It is clear that the domestic relations are most significant for most types of collaboration partners.

The innovation system of all four technology areas are influenced by the pronounced Danish tradition for discussing the energy area and broad popular engagement. In general many actor groups appear in the innovation systems. It is not only one type of actors e.g. research actors, industrial manufacturers or the energy companies.

Apart from formalised co-operation also informal interaction and discussions in broader forums are of high importance to energy technology development. A survey shows that 60% of the energy actors as part of their activities participate in debates and broader discussions e.g. in media debate, in public debate meetings and hearings, and in meetings in interest organisations. Also discussions in experience networks are important to many. These activity patterns constitute a strength position of the energy innovation system.

There is considerable amount of public-private co-operation in the Danish energy innovation system. One of the places this appears clearly is in the public R&D programmes where many of the projects are collaborations between private and public actors. The collaboration projects are often between private business companies and public research institutions, however also other types of collaborations, e.g., between companies and local or regional authorities occur. Public-private partnerships are a part of normal practice and have been so for many years. Public-private partnerships are not in themselves a ‘new solution’ to the energy area or a policy instrument that will offer significant new dynamics to the innovation and development in the energy area.

There are limited educational activities on the individual technology areas though education in wind energy to some degree has developed in recent years. Also in the area of hydrogen and fuel cells there are higher education activities. In the other areas it is relatively scattered. The picture is similarly scattered concerning more general energy-related educations.

For the technology areas that have created significant changes in the energy systems, policy efforts have been a main driving force for the changes. In recent years, few new regulatory efforts that can drive energy innovation and improve the energy systems have been established, though there is huge attention to the energy area, climate problems, etc. Need integration through national regulation is becoming less pronounced and a weaker driving factor for innovation than earlier.

Apart from in the wind energy area, the market-oriented policy instruments employed in order to change the energy systems in a more sustainable direction have not in themselves ensured drastic changes. The economic incentives are in most cases not large enough to lead to radical change, or they have been too rigidly employed. A clearer strategic edge on the market-based efforts is needed.

3. Renewable energy innovation systems in Sweden

Co-author on this chapter: Hans Hellsmark

3.1 Introduction

Renewable energy has a prominent role in the Swedish energy system. The input of bioenergy was as high as 110 TWh in 2004.[9] This is mainly used for heating purposes. Power production is to a great extent carbon neutral, mainly due to a supply of about 70 TWh hydropower (Energimyndigheten, 2007, tables 22 and 27), including more than 2 TWh of small scale hydro in 2007. Additionally, in 2007, there was a supply of nearly 10 TWh of biopower and 1.4 TWh of wind power. In the transport sector, alternative fuels account for a higher share than in most countries. A great deal of progress has, thus, been made towards an energy system that is carbon neutral. Much remains to be done, however. In what follows, we will give a brief account of the actors and networks; the patterns of needs-integration and the effects of that needs-integration for four new energy technologies that today account for a smaller part of the energy supply but which have a large potential. We will also point to challenges for policy in terms of realising this potential. Before doing so, we will however outline some structural elements in the Swedish energy sector that need to be understood prior to delving into the individual case studies.

First, the Swedish power system is based largely on hydro power and nuclear power. In addition to a well-developed hydro power base, a very large capacity for nuclear power was built in the 1970's and 1980s (power supply of 67 TWh in 1986, see Energimyndigheten, 2007, table 22 and 27) with expectations of a future continued rise in demand for power. These expectations were, however, not fulfilled and the price of power was therefore kept at a very low level for many years, which, of course, discouraged any new investment in power technologies.

The low power prices suited the energy intensive Swedish paper and pulp and steel industries, who became staunch advocates of nuclear power. These industries are prominent in the Swedish industrial landscape and of very considerable economic importance which meant that the advocacy coalition for nuclear power came to involve key organizations in Swedish society. Since the 1980s, the low price for nuclear (and hydro) power and a very active advocacy from nuclear power proponents (over the hearts and mind of both the general public and politicians) are major factors to consider when we analyse the development and diffusion of new power technologies.[10] Indeed, the value of maintaining a low price for electricity came to be a prominent institutional feature in Sweden, unlike for instance Germany, where a great value is also put on the development of a German capital goods industry. This lack of emphasis on industrialisation opportunities connected to new power technologies is relatively recent in Sweden. Only a few decades ago Asea built up a business in nuclear power plants and Sweden had a good industrial base in electrical engineering related businesses[11] as well as in boiler manufacturing. Similarly, policy documents used to emphasise industrialisation opportunities but in the last two decades, references to such opportunities have been sparser.

Second, there was an early expansion of district heating systems in Sweden. Unlike Britain or Continental Europe, much of the heating in the cities and smaller communities is done through district heating pipelines. The heating is generated in boilers which then add to those installed in the extensive paper and pulp industry to generate process steam. Again unlike Britain and the Continent, the gas grid is underdeveloped and currently exists only on the south west coast. The extended district heating grid, the large paper and pulp industry and the small gas grid are major factors impacting on the current development in biomass based CHP.

Third, two major regulatory changes in the last two decades are central to the analysis below.

- A first originated from a three party agreement on energy in 1991 (Centre, Communists and Social Democrats). The agreement was made against the backdrop of a 1988 decision to start the

[9] Total energy supplied was 647 TWh but out of these, conversion losses in the nuclear power stations amounted to 149 TWh (Energimyndigheten, 2005).
[10] For further readings on this 'nuclear trauma', see Jacobsson and Johnson (2001), Bergek and Jacobsson (2003) and Jacobsson and Bergek (2004).
[11] ABB sold its power generation business in the end of the 1990s.

dismantling of nuclear power (following a referendum in 1980), of a growing awareness of the role of fossil fuels in climate change and a decade or more of efforts to reduce oil dependency (Jacobsson, 2008). The agreement meant that a) a CO_2 tax was introduced (and gradually raised) leading to a rapid diffusion of biomass for heating purposes (Kåberger, 2002) b) the build up of an embryonic natural gas grid was until recently halted, c) investment support for renewable energy technologies (mainly wind turbines and biomass CHP) was initiated and maintained until 2002. New power capacity was needed if the decision to dismantle the nuclear capacity was to be implemented. The low price for power gave, however, no incentives for investors. Indeed, for biomass CHP, the low price was broadly equal to variable costs only (Energimyndigheten, 2001, p. 57). An investment support was, therefore, required for a diffusion to take place.

- Largely as a result of an exogenous factor, pressures from an EU Directive, a tradable green certificate scheme was initiated in 2003. The scheme gave support for renewable energy technologies and involved a much higher level of ambition for the diffusion of these technologies than the investment subsidy programme of the 1990s (Bergek and Jacobsson, 2008). The current duration of the scheme is to 2030 and is of major importance for an analysis of the diffusion of power production technologies using renewable energy sources.

3.2 Biomassed based CHP and gasified biomass

Actors and networks

Biomass has central position in the Swedish energy system in terms of heat supply. Excluding large scale hydro, biomass based CHP is also emerging as the single most important renewable energy source for power production with a supply of nearly 10 TWh in 2007. The Nordic (nowadays mainly Finnish) equipment industry (boilers etc) is very strong with world leading companies Foster Wheeler, Metso Power and Wärtsilää. The Swedish subsidiary of Kvaerner (former Götaverken) used to be one of the leading companies in the world in the supply of boilers for biomass. Yet, after acquiring the Finnish firm Carbona a few years ago, production of boilers was shifted to Finland (Olofsson, 2005). Moreover, Kvaerner was recently acquired by Metso Power.

The strength of the Nordic equipment industry is induced by a large local market in district heating and in the paper and pulp industry and by tight emission standards (Jacobsson, 2008). There is also a good academic knowledge base in combustion as well as strong networks between universities and industry (Jacobsson, 2008). The knowledge base was early diversified into gasification of biomass (both solid and liquid) and a world leading application in CHP was built in early 1990’s in Värnamo by the Finnish firm Ahlström (later acquired by Foster Wheeler). This early lead was not, however, sustained.

Patterns of need integration

The extensive district heating system and the large paper and pulp industry are basic structural factors driving a needs-integration. The huge forest based industrial structure has generated well developed supply chains and cheap raw materials in terms of waste wood and waste from industrial processes. The low price of nuclear and hydro power meant, however, that it required regulatory changes in the form of investment subsidies (in the 1990s) and the tradable green certificate scheme (in 2003) for investments to take place on a larger scale in biopower.[12] A further contributing factor to current investments is explicit preferences for ‘green’ technologies, in particular by Council owned district heating suppliers (Jacobsson, 2008), some of which were among the pioneers in the 1980s (Hellsmark, 2005; McCormick and Kåberger, 2007).

There is recently a revived interest in gasified biomass, much (but not only) driven by an exogenous policy initiative in the form of the new EU proposition of a 10% share of biofuel by 2020. In Sweden, there are high expectations from the transport industry, in particular articulated by the CEO of AB Volvo Leif Johansson. The IGCC plant in Värnamo (built by Ahlström and Sydkraft, now EoN) is planned to become a centre for R&D/demonstration of a ‘solid fuel to synthesis gas process’ with the help of demonstration funding from the Swedish Energy Agency. In Piteå, black liquor (an energy rich by-product in the paper and pulp industry) is to be gasified and turned into transport fuel (DME). An early development of this technology (aimed then at power production) was pushed by policy in the 1990s, but the paper and pulp

[12] Some commercial investments were made by the paper and pulp industry.

industry was then not interested in taking the risk to replace a central component in their production process (Bergek, 2002).

Effects of the patterns of needs integration and key policy challenges

With the tradable green certificate scheme, output of biopower rose from 3.9 TWh in 2002 to 9.58 TWh in 2007. Although most of this increase was made within already existing plants, there is currently a huge interest in new investments (Jacobsson, 2008). In this scale sensitive technology, also smaller scale applications are being explored (Jacobsson, 2008). The potential is large. With current technology, it may be in the order of two and half to three times current output (Jacobsson, 2008) although these expectations are contested and limited to core actors in the industry. Indeed, in the heated Swedish debate over the future of the power system (in particular the future of nuclear power) the potential of substitutes to nuclear power has always been played down by advocates of nuclear power. A particularly telling example is an editorial in the leading daily newspaper Dagens Nyheter (1996) which, quite erroneously, claimed that:

> "Firewood can't replace nuclear power…Biofuels can give us a marginal addition, but not even with maximum production can they, with respect to power, replace more than one nuclear power reactor (our translation)"**.**

Another effect of the needs integration is a development of the steam cycle technology. Steam pressure is being increased (increases output of power) and a modularization (lower scale disadvantages) is driven by the Finnish firm Wärtsilä. Finally, new and cheaper ways of building district heating pipelines are developed.

Although the innovation system in Sweden is quite strong, there are some policy issues that need to be handled (Jacobsson, 2008). First, there is a competition over the regulatory framework between advocates of natural gas and those advocating biopower. This competition induces an unnecessary uncertainty for investors. Second, the tradable green certificate system has the drawback that the price of the certificates is very difficult to predict and is, therefore, an additional source of uncertainty for investors. Conventional steam cycle biopower, therefore, meets two sources of uncertainty that may hamper investments.

For gasified biomass, the efforts to form an industrial consortium to co-fund the Värnamo demonstration plant has met with problems (allegedly over the IPR rights) and the Swedish Energy Agency has frozen its subsidies (writing in April 2008). The plan to upscale the pilot plant in Piteå for black liquor gasification seems though to progress well. With demonstration funding from the Swedish Energy Agency (SEK 100 million), risk capital from Volvo and a US based venture capital firm (to strengthen Chemrec, a smaller engineering firm), a paper and pulp company is now investing in a demonstration plant (a parallel investment will take place in the US).

3.3 Solar cells[13]

Actors and networks

Solar power has a very weak position in the Swedish energy system. Up until recently, the market was constituted by off-grid applications (e.g. summer houses) but grid connected applications are now emerging as a consequence of a recent market formation a programme (see below). By 2007, the total installed effect amounted to 4.8 MW (IEA, 2007a), equalling a supply of about 4 GWh. The innovation system is immature and, in particular, disconnected. There are two cell manufacturers of which one (Solibro) is an academic spin-off from Uppsala University that recently formed a joint venture with a German firm for the commercialization of Solibro's advanced thin-film technology. The other firm (Midsummer) is a start-up going for a different type of thin film technology. Their local networks include links to both Chalmers University of Technology and Linköping University as well as to the steel manufacturer Oitokompo (Ny Teknik, 2008). Apart from some funding and knowledge formation, these two firms have, however, no links to the rest of the Swedish system.

Another part of the innovation system consists of five module manufacturers with growing production capacity, indeed perhaps the most dynamic part of the innovation system. These import cells and export complete modules, mainly to Germany. The firms are largely de-linked from the Swedish (academic)

[13] This section is based on work carried out together with Björn Sandén, Linus Palmblad and Johanna Porsö.

knowledge base and from the Swedish market. A third set of actors are engineering and consultancy firms who design and deliver complete solar cell installations. There are a growing number of these who exploit the market created by public subsidy programme.

Patterns of need integration

The evolution of the innovation system is a response to quite different factors. First, Solibro is an effect of public R&D funding at the Ångström Laboratory in Uppsala (origin also at KTH in Stockholm). Induced by the funding agencies (MISTRA and Swedish Energy Agency), the academics formed a company in order to commercialise their top class work (in a global perspective).[14] Midsummer, on the other hand, is a private start-up but it draws upon the microelectronics competence in Kista coming out the work of Ericsson (and presumably from a strong effort by STU (predecessor of VINNOVA) to form such competence in the 1980s, Jacobsson, 1997). Second, the module manufacturers respond to the climate policy debate and, in particular, the exceptionally strong demand for modules in Germany. Third, the current market formation programme on public buildings, involving subsidies of in total SEK 150 million, has not only led to an acceleration in the diffusion of solar cells but also led to an entry of a number of firms ‘down streams’. A considerable learning has taken place, including learning about institutional obstacles to further diffusion (Porsö, 2008).

Effects of the patterns of needs integration and key policy challenges

As outlined above, the innovation system for solar cells is very immature. To the extent that this technology is seen as socially desirable in the Swedish context, there are a number of policy issues related to a further development of the innovation system. First, up until recently, there was a paucity of risk capital. Indeed, Solibro (and others) put a lot of efforts into attracting Swedish capital for an up-scaling of their technology (world class) but there was no interest among the large Swedish firms to invest (Malmqvist, 2000). Recently, with the growing focus on ‘clean tech’ the situation may be changing. Midsummer seems to have no problems in attracting capital, although at a much lower level so far than what Solibro required (and which were eventually supplied by the German firm QCell).

Second, there is no market place for solar power, i.e. individual consumers can not choose to buy, say, 100 kWh solar power a year. The large utilities that dominate the market do not offer this product. Among the smaller utilities, there has been an interest but a product has not materialized. This means that consumer choice is restricted and that the opportunity for market skimming is neglected. A part of this issue is to solve the problem of grid connection of decentralized power technologies. Currently, the grid operators charge so much that there is no point selling solar power generated in smaller plants, say on a roof top.

Third, among the actors, there is an absence of a vital category, namely architects and the building sector, in part due to low expectations of the future of solar cells in Sweden. These expectations are, furthermore, fuelled by a lack of interest by the utilities in solar cell investments. Fourth, the innovation system is, as argued above, disconnected whereby a growth in one part does not build on, or impact on, other parts. This lack of integration may prove to be a weakness, in particular the absence of a demanding home market may limit its innovative strength.[15]

3.4 Wind turbines[16]

Actors and networks

Wind energy has a weak and strongly contested position in the Swedish energy system. Although the rate of diffusion has increased in the last two years, only 1.4 TWh were supplied in 2007. This can be compared to Germany (a smaller country and much more densely populated) where the supply was about 30 TWh. The Swedish potential is very large in relation to current supply – recently the Energy Agency set a goal of 30 TWh by 2020.

[14] There are also other entrepreneurial experiments in the system, see Porsö (2008).
[15] Jacobsson and Sandén (2004) argued for a Nordic solar cell policy.
[16] This is based on work done together with Anna Bergek (Jacobsson and Johnson, 2001; Bergek and Jacobsson, 2003 and Jacobsson and Bergek, 2004) as well as Bergek (2008).

Three decades ago, the Swedish position was, however, much stronger in relation to other countries but all entrepreneurial experiments where the objective was to develop a supplier industry failed in a very hostile environment. The central reason behind this failure was a poor legitimacy for the technology – it was not seen as a socially desirable technology, neither by industry nor by media or in large part of the population. For industry, it was not seen as a significant contributor to the energy supply but rather as a threat to existing nuclear capacity. As it was posed as a threat (to the energy intensive industry), its potential to contribute to the power balance was played down[17] as were the industrial growth opportunities associated with wind energy. Additionally, for large parts of the population, the cultural meaning of the technology was rather one of 'polluter of landscapes' than a 'supplier of clean energy' (Bergek, 2008).

ABB did not diversify into wind turbines until it had divested its conventional and nuclear power production technology in the second half of the 1990s. It then attempted to drive a discontinuous change in the wind turbine industry involving a new technology and a new application (off –shore) but later withdrew. Today, there is only one firm trying to develop a wind turbine business, Morphic. Until very recently, their wind power activities were based on a license from a Finnish firm, but in June 2008, they acquired 80 per cent of ScanWind AS, a Norwegian firm (Morphic, 2008). This company stems, in part, from Kvaerner Turbin which was one of the Swedish firms that tried, but failed, to develop in the 1980s and 1990s in Sweden (Bergek and Jacobsson, 2003). There are, however, other firms with a strong position as suppliers of components. One of these is SKF which has a large market share for bearings for wind turbines. ABB (Finland) has a good position for generators. There is also a local tower production business. In addition to these equipment suppliers, there are some firms planning and building wind turbine parks, on as well as off-shore.

Patterns of need integration

The diffusion of wind turbines has, hitherto, been very slow (mainly induced by investment subsidies as from 1991). Around 2003, the context began, however, to change and investments in wind power were driven by three quite distinct types of needs integration. The first were changes in the regulatory framework. The most important was the introduction of the tradable green certificate scheme. It did not initially have an impact on investments in wind turbines but began to have so after the scheme was prolonged to 2030 (reducing investors' perceived uncertainty). Rising power prices, partly induced by the introduction of tradable emission rights have given additional incentives. Finally, some subsidies have been introduced to off-shore applications. Policy has, therefore, begun to have a greater impact recently.

A second change has been the climate change debate and an associated growing legitimacy for wind turbines. A turning point was, perhaps, when the CEO of AB Volvo, which is the largest company in Sweden, made a public stand for wind energy a few years ago – being the first senior CEO who has advocated carbon-free as well as nuclear-free power for his firm. Related to a growing legitimacy has been a rapid growth in 'clean tech' savings opportunities, often marketed by illustrations of wind turbines.

A third change has been a repositioning of the base industry vis-à-vis wind power. From being intensely anti-wind power when it was put forward as a substitute to nuclear power in the 1980s and 1990s, the base industry, e.g. SCA, is now integrating backwards to power production and wind power figures here prominently. The backward integration is driven by a desire to escape some of the volatility of the deregulated power market and to secure reasonably cost power.

Effects of the patterns of needs integration and key policy challenges

These recent changes have lead to an increase in the diffusion; the output of wind power was raised from 0.86 TWh in 2004 to 0.99 in 2006 and to 1.43 TWh in 2007. More importantly, they signify a complete turn-around in industry's interest in investing in wind turbines. This reflects a major improvement in the legitimacy of wind power and large investments are now being planned in the forests so as to avoid the extremely lengthy and uncertain applications for permission that have hitherto been a major obstacle to the

[17] A potential of 20 TWh or more has been put forward by wind power proponents since the 1970s (currently the position of the Swedish Energy Agency is that it is 30 TWh). However, a scrutiny of the major Swedish daily newspapers for articles that mention wind power reveals that more than 80 percent of these described the potential or actual wind power contribution as "small" or "smaller than some other electricity source". These negative expectations on wind power, communicated through media, have not been counteracted by policy makers in a forceful way (Bergek et al, 2008).

diffusion of wind turbines (Bergek, 2008). The recent announcement of the Swedish Energy Agency of a goal of 30 TWh in 2020 (instead of 10) also reflects a growing legitimacy.

The main obstacles, and policy challenges, for the future lie in

- An absence of a local wind turbine industry which may lead to very long lead times. The failure of Sweden to develop a wind turbine industry in the 1980s and 1990s implies not only that Sweden lost out on a major growth industry (in spite of having all the required technological capabilities) but also that the rate of diffusion may be limited by longer term imbalances between demand and supply capacity of the global wind turbine industry.
- The unresolved procedures to get building permission which has plagued the industry for many years.
- The ceiling put on the diffusion of renewable energy technology set by the quotas of the tradable green certificate scheme may act as a limiting factor to the diffusion (if the other two obstacles are resolved).

3.5 Fuel cells and hydrogen[18]

Actors and networks

Fuel cells have hitherto a very weak position in the energy system but over the past decade or so, an embryonic innovation system has emerged. The dominant actors and networks centre on a 10 year long MISTRA funded programme.[19] SEK 100 million is channelled to academia and industry contributes with the same sum. The main academic actors are the three large technical universities in Stockholm, Gothenburg and Lund. The firms involved, or having been involved, in the programme range from the large MNCs, to a steel manufacturer, a private start-up and academic spin-offs. They include: Ericsson (left), ABB (left), AB Volvo, Oitokompo, Cellkraft (spin-off KTH), Powercell (Volvo-Statoil), myFC (spin-off KTH), Nolab, Morphic, Tanso and Timcal. Within the MISTRA programme, the networks are strong. In addition to this network, Hydrogen Sweden is an organisation lobbying for a hydrogen highway in Western Sweden.

Patterns of need integration

A key driver of the innovation system is, thus, the funding by MISTRA. The needs integration is, however, driven also by other means, in particular various types of niche markets. AB Volvo's (Powercell) interest is driven by the US market where the opportunity to use fuel cells as an auxiliary power unit when the truck engine is turned off (saving fuel and reducing emissions) is an attractive niche application.[20] Other niche applications are constituted by power production in remote areas, such as in the Antarctis, back up for telecom stations (Cellkraft) and mobile phone chargers (myFC). In addition, there are subcontractors involved in the embryonic system (Nolato in polymer components and Timcal in surface treatment) and a supplier of steel (Oitokompo).

Effects of the patterns of needs integration and key policy challenges

As mentioned above, a number of entrepreneurial experiments have been set up in association with the Mistra program and the opportunities with different types of niche markets. An interesting additional entrepreneurial experiment is that of Morphic which is a private start-up producing fuels cell plates and wind turbines as well as small scale systems. As mentioned above, they license the wind turbine technology but the know-how for the plates is derived from military production in the same region. This knowledge involves the ability to shape the bipolar plate with great force (in large volume and great speed). More support is given from the region in that KEMAB (a public sector environmental and waste company) has bought 20 per cent of smaller demonstration plant using wind turbines and fuel cells. Currently, Morphic received a fairly large order for fuel cell plates from electronics manufacturers in Asia and the US and they

[18] This section draws heavily on the deep knowledge that my colleague Bengt Steen has on the development in Sweden. Professor Steen is a co-leader of a large and 10 year long MISTRA programme on fuel cells in Sweden (Steen, 2008).
[19] Initially, this programme focussed on batteries but has a small presence in fuel cells. When some Japanese firms took over that market, the programme shifted emphasis to fuel cells.
[20] Other mobile applications, like ships, are also of interest (MISTRA, 2008).

have received an order from Greece for a fuel cell based system. The total order stock is currently (January 2008) about SEK 200 million.

The weaknesses in the innovation system centre of lack of longer term academic funding and the low level of it. Whereas the MISTRA funding has been long term, the overall funding of Swedish R&D in fuel cells is quite low. Indeed, the level of publicly funded R&D is estimated to be only 1/10th of that of Germany (MISTRA, 2008). Associated with this is a poor supply of competence, in terms of trained individuals and a questionable ability to rapidly upscale the supply of trained people. Another challenge is to attract Swedish based MNCs (apart from Volvo) to enter into the innovation system in order to find new applications and to reach final customers.

3.6 Concluding remarks – Swedish energy innovation system

In these four new energy technologies, Sweden is not in the forefront. The diffusion only started very recently, even for the more mature technologies of conventional steam cycle biopower and wind power. [21] For solar cells and fuel cells, Sweden is a very marginal country. Sweden is also lagging behind in terms of developing the associated capital goods industry (with the exception of Kvaerner's business in large biomass boilers which, however, is now in Finnish ownership and where production is located in Finland) and in driving innovation processes in these technologies.

Two partial, but deep rooted, causes of this poor performance are a) the low price of power since the expansion of nuclear power in the early 1980s and b) the long standing conflict between advocates of nuclear power and those that advocated renewable energy technologies which has meant that renewables has faced a very stern and organised opposition. Indeed, it is not surprising that it required a largely exogenously driven regulatory change (TGC) to set in motion a diffusion of some magnitude. It is only in the past two years or so that the conflict has been tuned down. Of course, without much legitimacy and without an early home market, entrepreneurial experiments in the new technologies have had poor chance of succeeding.

The whole nuclear issue (including the low price of power) has, thus, been like a wet blanket over the Swedish power sector and stifled entrepreneurship and innovations (again with the exception of biomass boilers). With a weak capital goods industry, Sweden is now reliant on imported equipment at the time when there are large imbalances between demand and the supply capacity globally. Unfortunately, whilst the tradable green certificate scheme is successful in fostering a market for renewables (biopower and wind power) it fails to induce entrepreneurship and innovativeness in less mature technologies (Bergek and Jacobsson, 2008). By placing a high value on short term cost efficiency, it, thus, maintains the Swedish focus on cost issues rather than on innovation.[22]

The market potential is, however, large but each technology faces its unique policy challenges. It requires a knowledgeable set of policy makers to design policies that may unleash this potential. Some of these policies may be applied at the Nordic level, an issue that we will come back to below in Chapter 7.

[21] There were, however, pioneers already in the 1980s. for biopower, see Hellsmark (2005) and McCormick, K. and Kåberger, T. (2007).
[22] This refers to cost efficiency in social terms. The price of the certificates is high and generates massive wind fall profits (Bergek and Jacobsson, 2008).

4. Renewable energy innovation systems in Norway

Co-author on this chapter: Joachim Hafsås

4.1 Introduction: Resources, Industrial Bases and Policy Context

With 23% of all hydropower; 59% of all oil and 39% of all gas in Europe, Norway is a central energy-nation in Europe. The country is also in a remarkable position with respect to renewable energy. 99% of electricity generation is hydro-based, and is experiencing a dynamic industrial development based on production of solar cells. Furthermore Norway has a unique possibility to produce energy from wind, biomass, tidal- and wave power, free of CO2 emission.

In its engagement in renewable energy, Norway draws on several industrial bases:

- Norway has over 100 years experience with hydropower and possesses considerable competencies in all parts of the hydropower value chain. This competency is utilised in small scale hydropower construction, and upgrading of the hydropower system to balance intermittent power from renewables.
- Closely linked to hydropower construction, Norway has built up a large industry in electro-metals and electro-chemicals, with considerable competencies in materials- and process-technology which is presently being utilised in solar cell production.
- With the extensive petroleum extraction from the Norwegian continental shelf, the country has developed an industrial offshore cluster which is currently engaging also in offshore renewable energy.
- With high engagements in paper and pulp industry Norway is also industrially positioned for engagement in second generation bio-fuel.
- Norway also hosts a world scale merchant marine, and a maritime cluster of industrial suppliers with a potential to engage in offshore energy production.

The Norwegian policy context is special in several ways. Firstly, with a fully renewable electricity generation, Norway has not felt the need for strong energy policy instruments to meet demand for clean energy. The unique resource base has given Norway comparative advantages in energy that could be traded on regional and global markets. Hydropower, indirectly through electro-metal and electro-chemical products, and gas and oil directly.

<u>The Energy Related Innovation System</u>
Considerable R&D has been mobilised to support Norwegian energy industry. However, there is a distinct difference in industrial structure and research engagement between the petroleum- and the electricity sectors in Norway that clearly spills over into their innovation:

- In the petroleum sector, a handful of large Norwegian and international energy companies are drawing on competencies from around a hundred Norwegian technology- and service-suppliers. The solutions that are developed in Norway for Norwegian conditions are thereafter transferred to international markets, helped by the large energy companies. This cluster engages actively with R&D institutions (Mikkelsen 2004).
- The electricity sector, on the other hand, is characterised by a large number of small and medium sized energy companies where a majority have municipal or regional focus, and where competencies and the main activity is focused on operation and maintenance of generators and distribution grids. Traditionally the electricity sector financed and coordinated extensive innovation through collective arrangements by the industry association. Following deregulation in the 1990s this system broke down and innovation was left more and more to individual companies (Thue and Nilsen 2006; Thue and Skjold 2007)).
- Very few of these companies have competencies, capacity or ambitions to undertake research driven innovation. On the supply side, there is a handful international companies, that, because of low new project activity do not see Norway as an interesting arena for development.
- The electrometallurgical and paper and pulp and maritime industries are fairly concentrated industries, with large scale global actors, capable of mobilising considerable R&D.

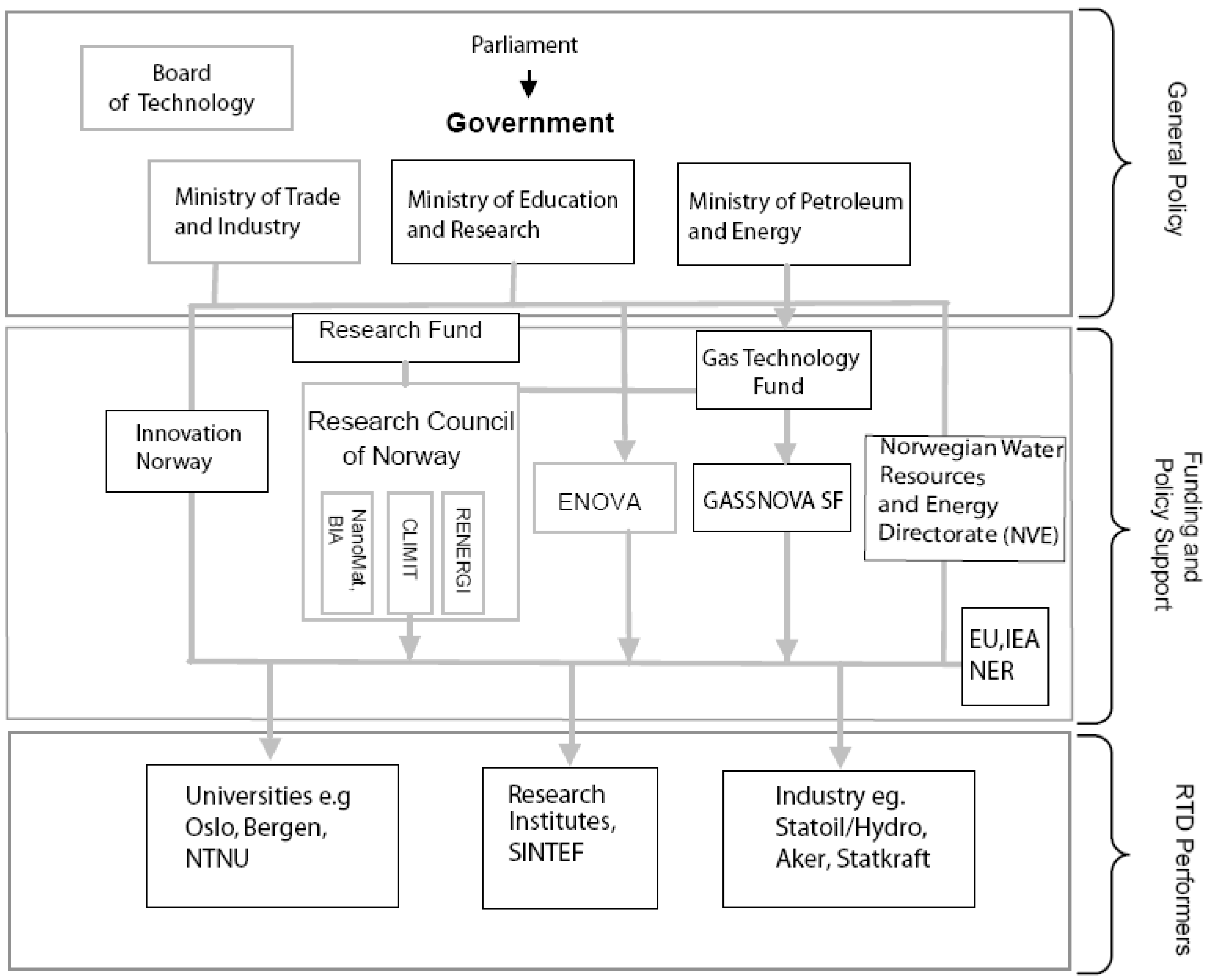
The most central research groups within renewable energy in Norway are Sintef, an applied research laboratory attached to the Norwegian Technical University, the Institute for Energy Technology, the University for Life Sciences. Sintef, NTNU and IFE are jointly running the Centre for Renewable Energy

(SFFE) which initiates innovative research into small scale hydropower, wind, solar, wave, and bio-energy as well as the social dimensions of energy use.

The most important government bodies involved in the Norwegian energy related innovation system are: The Ministry of oil and energy, the Energy Directorate (NVE); the Oil Directorate (OD); Enova, established to further environmentally friendly transformation of the energy system; Innovation Norway which promotes nationwide industrial development by contributing towards innovation, internationalisation and promotion and the Research council of Norway with several energy-focused programmes.

An overview of the Norwegian energy policy and innovation system is given in figure 17.

Figure 17: The Norwegian Energy Policy & Innovation System: Source NIFU STEP (Klitkou et al 2008).



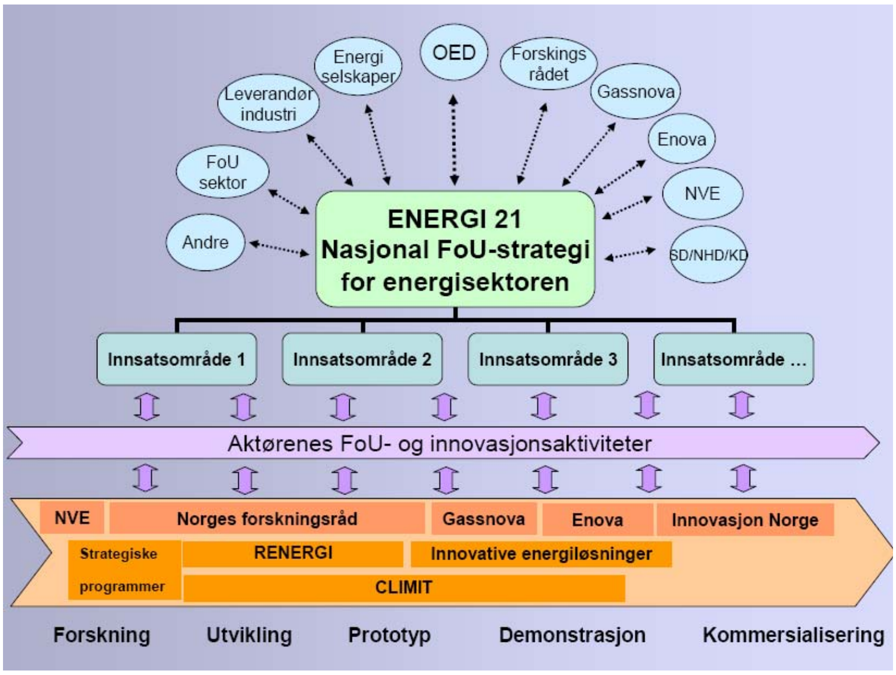
In a more extensive analysis, the innovation system also includes industry associations that are active in shaping industrial research agendas including:

- OLF, the Norwegian Oil Industry Association, which is a professional body and employer's association for oil and supplier companies engaged in the field of exploration and production of oil and gas on the Norwegian Continental Shelf. OLF's task is to lead the industry's joint effort for development of a progressive and competitive petroleum industry.
- EBL, the Norwegian Electricity Industry Association, which is a combined industrial and employer organisation for the electricity industry. Their goal is to work towards better framework conditions for their members.

- Smaller renewable energy associations like the Norwegian solar energy society, that promotes the utilization of solar energy in Norway through education, research, technology development and marketing and the Norwegian Wind Energy Association; which is working for to utilize Norway 's large wind resources.

Recently the National programme Energy 21 has mobilised industrial, regulatory and research actors into a joint effort with a mandate to establish a broad strategy for the energy sector that brings together a wide-range of R&D goals and communities (figure 2). The objective of the strategy has been to provide a platform for a sustainable energy sector by promoting and coordinating a commitment to research, development, demonstration and commercialisation of new technology. Two of their five targeted programme areas are related to renewables: 1) "more climate friendly power - from water, wind and sun"; 2) CO2 neutral heating – increased exploitation of bio-resources and local heat sources". And a third programme: "An energy system for the future" is focuses on the necessary framework conditions.

Figure 18: Energi 21: National Initiative for Energy R&D; actors and arenas. Source: Energi 21.



To sum up, Norway hosts a strong and consolidated petroleum-innovation system. el-innovation system in electricity is more fragmented and particularly weak on commercialisation instruments (hydropower sold itself). Renewables are providing new linkages: ex offshore wind, engaging both petroleum and electricity systems.

The following sections discuss the innovation systems around particular renewables: bio-energy, solar cells, hydrogen and fuel cells, wind power and small scale hydropower.

4.2 Bio-energy

Actors

The joint resource outtake from agriculture and forestry in Norway is 55TWh, where 16 TWh goes to energy production and the rest to construction, paper and pulp industry and food. Burning of wood stands for 6-7 TWh and heat production in paper and pulp industry, the sawing industry and sales of wooden materials the sawmill industry and the building materials industry stands for about 7 TWh. The last 2-3 TWh comes from waste, landfill gas, other biogas (KanEnergi, 2006).

Commercial Actors

The actors in the bio power market have traditionally been energy companies, including the agency for energy extraction in Oslo and Trondheim Energy. Over the latter years a number of medium sized and large industrial actors have shown interest for bio power and invested in positioning themselves in this field. One example in Aker Kværner's engagement in combining electricity generation from natural gas and biomass (Just Catch technology). Industry in Norway has shown an increased interest in this field. Other actors are: Bio Varme AS, Solør Bioenergi gruppen, StatoilHydro, Statkraft, Eidsiva Energi, Agder Energi, Trønder Energi, Sødra Cell Tofte, Biogas AS, Conbio AS, INC, Energos and Norsk Inova. According to Energi 21 (2007), there is a trend that energy companies that own and manage large systems, also involve more heavily in developing next generation technology in their field.

Organisations and Public Authorities

Bio energy is organised around several foci: The Norwegian Forest and Landscape Institute, the University of Life Sciences and the Norwegian Institute for Agricultural and Environmental Research are focused on the resource side of bio-energy. The technological issues are handled by the Norwegian University of Science and Technology, SINTEF and the Centre for Renewable Energy. ENOVA and Innovation Norway provide both economic support and consulting to bio-energy actors. Norsk Bioenergiforening is the largest interest organisation within the sector.

Patterns of Need Integration and Learning

Norway has R&D competencies on the bio-energy resources with the University for Life Sciences at Ås, particularly their wood, landscape and bioresearch branches, and within convertor technology (SINTEF, NTNU). Examples of other actors are the Centre for renewable energy, ENOVA and the Norwegian bio energy association.

Norwegian research and development institutions have also over time established close interfaces with foreign actors like Vattenfall in EU projects, where the main focus is on electricity generators from bio fuels.
The Norwegian government has in white paper nr 34 (Stortingsmelding nr 34, 2006-2007 decided to increase bio energy production with 14 TWh by 2020. The support from Enova to renewable heat-based energy has been 917 million kroner since 2002 with more than 2,5 TWh contracted . In 2007 the support amounted to 322 millions kroner with 751 GWh production of energy contracted. It is expected that this support programme for heat-based energy will be substituted with three new programmes.

In the Parliamentary White paper nr 11 (Stortingsmelding nr 11, 2006-2007), immature technologies may have additional support with up to 10 øre pr KWh and investors may maintain this support for up to 15 years. However, the support will be cut by 0,6 øre for each øre increase of the average price at on the Nordic electricity exchange beyond 45 øre/KWh for one year.

Resulting picture

In spite of extensive non-utilised forest resources and competent R&D institutions, Norway has not built any strong bio fuel cluster. The yearly increase in biomass that may be used for bio-fuel is estimated to 140 TWh. Much of the biomass is, however, either to expensive to extract or it is used for other purposes, like wood for buildings and paper.

Compared to Sweden, Norway consumes relatively less bio-energy. This may be explained in part by differences in industrial structure, but also by the fact that Sweden has a far mor extensive district heating production than Norway (Langerud 2007)

The largest challenge for bio power is to be able to exploit the resources that are present in Norway and to develop new technology that increases the power efficiency. With today's technology and in a large plant (100MW+) the electric power efficiency is about 40 percent, in small plants (<1MW) the efficiency is typically around 5-10 percent. As pointed out by Bjørnstad et.al. (2003) more extensive production must also be seen against the backdrop of the current debate of its ecological sustainability.

4.3 Solar Cells

Actors

The Norwegian solar cell industry started in the 1970s at SINTEF in Trondheim and at the Institute of Physics at the University in Oslo. However, it was only with the focus on solar energy as a major contribution to solving the climate challenge in the 1990s that Norwegian solar energy experienced a boom. Since then, Norway has developed a solar cell industry, and Norwegian companies are currently engaged in several positions along the solar value chain (figure 19).

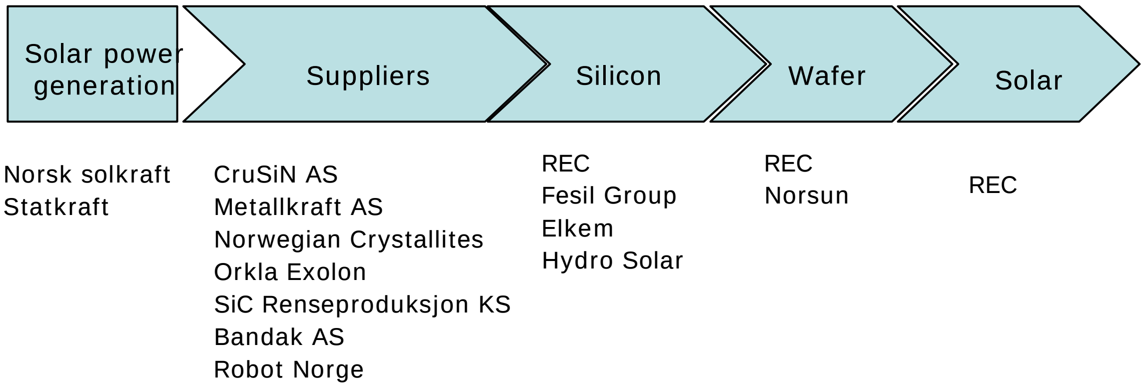


Figure 19: Norwegian industrial engagements along the photovoltaic value chain

The solar industry in Norway was in 2007 valued at over 120 billion NOK, dominated by one company: Renewable Energy Corporation (REC). REC emerged out of a merger of Scanwafer, Solarenergy AS and Fornybar energi AS. REC produces pure silicon for solar cells in the USA; silicon wafers in Glomfjord and Porsgrunn, solar cells in Narvik and panels in Arvika, Sweden. Today only REC produces the whole value chain and the solar cell modules.

Elkem ASA is one of the largest producer of ferrosilicon and silicon metal through Elkem Solar and has been involved in this since the 1980s, They are investing in new production technology for solar cell silicon in Kristiansand and are expected to market their new product in 2008. A large part of the production is already sold for delivery in the comming10 years. In addition Fesil and Hydro Solar are engaged to establish new production methods for developing solar cells from pure silicon. Norsun is establishing a plant in Årdal to produce monocrystal silicon wafers for solar cells. Production started in 2008. A large part of this production is already sold up front.

The solar cell industry has fostered a considerable supply industry. Orkla Exolon has a significant production of silicon carbide for wire based sawing of silicon wafers. SiC-processing is already established in Porsgrunn to re-circulate the waste from the sawing process. Robot Norway, Bandak, and several other engineering companies are supplying products and services in considerable volumes. Other start-ups are Metallkraft, Norsk solkraft Crusin, Norwegian Crystalites, and Bandak. Norsk Solkraft AS and Statkraft are focusing on solar power plants.

Patterns of need integration and learning

On the supply side, the development of the Norwegian "cluster" in photovoltaic cells has drawn heavily on technology and industrial competencies from the electro-metallurgical industrial complex. The solar cell industry is strongly related to market for silicon with high purity, in microelectronics, niche market for products like satellites, watches, calculators, battery charger, telecom and mobile communication (Christiansen, 2002). Solar energy is already fostering a new industrial branch in Norway, and is still triggering industrial growth.

On the demand side, the big leap forward for Norwegian solar cell industry in the 1990s came in response to the strong political mobilisation in Europe for solar energy to meet the challenge of climate change. Norwegian solar cell industry is therefore basically export-led. In spite of niche markets in Norwegian cabins and boats, which givers Norway a high pr. capita solar cell intensity, the volumes are abroad.

The Norwegian solar cell industry is research driven, with a close interface between universities and research institutions and operative industry. The Institute for Energy Technology has institutionalised its engagement in photovoltaics and built its own department for solar power with international expertise within development of methods and processes for production of solar cells based on silicon. The Norwegian University of Science and Technology (NTNU) has made solar power an issue in its own centre for renewable energy. They are both cooperating closely with Sintef for larger research and development projects and programmes, where they are trying to maintain Norwegian industry's position together with large industrial actors such as Elkem Solar, REC and Fesil AS.

Solar energy is also backed in Norway by the Norwegian Solar Energy Society. They promote the utilization of solar energy in Norway through education, research, technology development and marketing. The society actively lobbies for political engagement to make renewable energy sources competitive on the national energy market.

Resulting picture

The Norwegian solar energy has managed to evolve as fast as it has by being far-sighted and grabbing opportunities when the energy-intensive industry in the rural areas in Norway was downsizing and the Norwegian Government was willing to stimulate new industrial engagement on old industrial sites where new local development has followed closure of traditional electro-metallurgical and electro-chemical industry (Virkkala et al 2006). Furthermore, the world is experiencing a shortage of solar grade silicon and the Norwegian solar industry is exploiting this.

4.4 Hydrogen[23] and fuel cells

Actors

Because of the historical experience with using hydrogen in industrial processes, Norway possesses important industrial players in the field and Norway's research communities are at the forefront of essential areas in the hydrogen related technology field.

There are oil and gas and energy companies - large industrial players involved in the Norwegian hydrogen effort. These players have been active in hydrogen energy and fuel cell related projects since the mid 1980s, and actually before the official Norwegian interest in hydrogen as a future energy carrier. Since the mid-1980's four larger fuel cell R&D projects was undertaken in Norway (Godoe and Nygaard, 2006).

Looking into hydrogen as an energy carrier to be able to integrate hydrogen as part of their energy portfolio or looking into possible spin-off companies, Norsk Hydro, Statoil now StatoilHydro, Statkraft, Norske Shell (Shell Technology) support R&D in the institute sector but also conduct in-house R&D activities, and initiate and take part in demonstration projects to keep themselves informed of the technological developments in the field and to build up competencies on hydrogen as en energy carrier. As pointed out by OECD (2006) innovation in the petroleum industry is carried out largely by industry with more limited roles played by government. Large firms, in particular, play a dominant role in Norway.

Hydrogen research has also mobilised petroleum supply industry. Aker Kvaerner / Aker Elektro have been part of a technology project concept with Norske Shell, Statkraft. And Prototech in fuel cell development; Det Norske Veritas in security assessments, certification, and standards; and Raufoss Technology in high pressure storage tanks to mention some. Fuel cells for marine use is of special interest for some Norwegian

[23] Base on parts of Anne Louise Koefoed's thesis on the Hydrogen economy in Norway.

actors. Det Norske Veritas has taken leadership in a project on fuel cells for ships. Other Norwegian partners in the project are the ship owner Eidesvik Shipping AS, the supplier of electrical and power electronics equipment Wärtsilä Automation Norway AS, and the ship designer VIK-Sandvik AS.

In the research and institute sector, the SINTEF Group is recognised for its work on materials technology in fuel cells and hydrogen technology; Institute for Energy Technology is also very active nationally, as internationally, working with design and simulations on hydrogen systems and basic research in particle physics. There is collaboration between the institute sector and the universities – NTNU and the SINTEF group just as the University of Oslo collaborates with IFE on research and development in hydrogen related technology and material technology projects. The State College of Agder also undertakes hydrogen related research and renewable energy demonstration. Combined there is extensive hydrogen production related technological competence as it relates to natural gas but also electrolysis, storage and materials technology.

The environmentally oriented NGOs in Norway have also engaged in hydrogen. The Bellona Foundation has advocated hydrogen activities and ZERO (Zero Emissions Resource Organisation), another NGO promotes hydrogen in transportation and works extensively in the coordination of demonstration projects (e.g. HYNOR the hydrogen road from Stavanger to Oslo). Both NGOs work with lobbying and promoting and connecting knowledge in the hydrogen area.

The Norwegian Hydrogen Forum (NHF) was established in 1996 as a non-profit organization to promote the advantages of hydrogen as an energy carrier. The organization brings together Norwegian industry, universities and research institutes with interests in hydrogen. The members are engineers and scientists working as professionals and experts in industry, R&D and academia. Company members are quite diverse which reflect the range in the hydrogen energy chain associated with diverse production technologies, distribution and use / applications.

Patterns of need integration and learning

June 2003, a national Hydrogen Committee referred to as the Aam Committee (chaired by Sverre Aam SINTEF) was appointed by the Ministry of Petroleum and Energy (OED) and the Ministry of Transportation and Communication (SD). June 2004, the committee submitted the Official Norwegian Report on Hydrogen as the Energy carrier of the future (NOU 2004:11).

The Ministries chose to follow up on the Committee's recommendation in the form of a Strategy document (August 2005) to target hydrogen as an energy carrier for transport and for stationary energy supply. In December 2006 the strategy document was followed up by an action plan.

The Action Plan of the Norwegian Hydrogen Council has called for an increase in public funding from 2006 levels of about NOK 75 million, to NOK 200 million in 2010 and the 6 consecutive years.

The Research Council of Norway supports and provides funding for hydrogen related activity from basic to applied research in the entire hydrogen chain from production technologies, storage, transport and use, as well as support to demonstrations projects. Funding comes from several sources with different objectives for their investments:

- RENERGI (Clean Energy for the Future Programme) Hydrogen a thematic area in the programme that focuses on new and renewable energy as opposed to petroleum related research. Funding from OED, the Ministry of Petroleum and Energy, and SD, the Ministry of Transport and Communications, funding hydrogen and other zero or low emission fuels and technology solutions for the transport sector.
- NANOMAT programme (Nanotechnology and New Materials) which predominantly concerns hydrogen storage and which is funded by the Ministry of Education and Research funding NANOMAT.
- Through Gassnova (Centre for Sustainable Gas Technologies) and the research programme for Natural Gas Power with Improved Environmental Performance (CLIMIT) funding has been awarded to hydrogen related gas scrubbing technologies with funding coming from OED.
- The Hydrogen platform which is a coordinating engagement for activities within hydrogen research, -development and demonstration[24].

[24] www.hydrogenplattformen.no

Combined these programmes coordinates the Norwegian research efforts on the hydrogen area.

Resulting picture
Norway has many of the preconditions necessary for investment in hydrogen. There are resources and competence to produce hydrogen on a large scale from water (electrolysis) and from natural gas. Norwegian industry produces considerable volumes of hydrogen as a by-product and / or use hydrogen as part of industrial processes. Accordingly, there is considerable Norwegian competence with construction and operation of hydrogen production plants with different process technology and with the handling of hydrogen.

Nevertheless, a hydrogen exploration strategy was not developed in Norway until the beginning of the second millennium, when hydrogen was mentioned in the Official Inquiry Report on Gas Technology, the Environment and Value Creation (Stortingsmelding nr 9, 2002-2003), and pointed to as the potentially most important energy carrier of the future.

4.5 Wind Energy

Actors

Onshore
Up to 2006 there was a relatively large expansion of wind power, but onshore wind power has faced recession because of poor framework conditions. Even though 18 actors have concessions for construction, they are waiting to build until framework conditions improve. Norway has 15 onshore windmill parks with over 300 MW wind power, where the Smøla park, provides half of the total production (Vindkraft.no, 2007)

Some of the largest producers of wind power in Norway are (NVE, 2007):
- Statkraft, with about 74 percent of all production, these sites are placed in Smøla (150MW), Hitra (55MW) and Kjøllefjord (40MW).
- Arctic Wind AS, owned by Norsk Hydro, the Dutch company Noun and Norsk Miljøkraft, with the wind power plant Havøygavlen (40MW) in Finnmark
- Trønderenergi Kraft AS, with the wind power plant Valsneset (11,5MW) in 2006.
- The largest suppliers of wind power in Norway are Bokn Plast/ Hig comp, Chapdrive, Kristiansand Jernstøperi, ScanWind Group and Umoe Mandal.

Norwegian companies have also started to engage abroad: NBT AS is a Norwegian entrepreneurial company that focusing on wind power in China, where they have got licence to construct for over 15000MW.

Offshore
Some companies have been moving their pilot-projects abroad in order to get more subsidies than it is possible to get in Norway, this means that much of the competence that has already built up in Norway will be lost and when more of the industry are moving abroad the more difficult it is to be independent from the oil and gas. The companies that have brought some of their technology abroad are: StatoilHydro with technology development and participation in a large offshore wind project in shallow waters outside the east coast of England. Fred Olsen is involved in offshore wind power projects outside the cost of Ireland. Some technologies are being kept within the borders; Statkraft has started a project to achieve 1000 MW in 2012, on 30-60 meters dept in the North Sea. Lyse has notified public authorities of planning a wind park on deep water outside Utsira in Rogaland, and the first phase, with a capacity of 25 MW may be in place in 2012. Vestavind Kraft has notified public authorities of a large project based on floating wind turbines and there are industrial actors with concrete plans for full-scale testing of pilot plants for floating wind turbines. Two Norwegian concepts for floating offshore wind power are on the development stage (StatoilHydro and SWAY). Both concepts are based on a combination of a Norwegian tower construction and imported wind turbines from Multibrids and Siemens.

The Havsulproject on the coast outside Møre og Romsdal has a goal to produce 4.2 TWh in three wind parks with grounded windmills. Several actors are positioning themselves for supplies to offshore wind power: this includes: Nexans, ABB, Eide Marine Services, Grieg Logistics, Owec Tower, Rolls Royce Marine, SWAY AS, NorWind, Rosenberg verft, Aker Kværner, ScanWind, Scatec, SmartGenerator og Chapdrive.

Norwegian research communities that contribute to offshore wind are SINTEF, NTNU, IFE, Metereologisk institutt and Kjeller vindteknikk. Furthermore Statkraft and Norges Teknisk-Naturvitenskapelige Universitet (NTNU) engage in cooperation to do research on offshore wind. A network between the actors has been established at the University, represented by the Forum for marine renewable energy (industry focus) and the Centre for renewable energy (energy focus).

The Centre for renewable Energy is a cooperation between Institute for energy technology (IFE), The Norwegian University of Science and Technology (NTNU) and SINTEF where wind power is one of the areas of research and developments. The focus lies on aerodynamic and structural optimization of wind turbines, wind turbine load analysis, offshore wind energy, simulation of wind in complex terrain, wind energy consulting, wind park planning in collaboration with Kjeller Vindteknikk AS and testing of wind turbines in cooperation with VIVA AS. Their projects are in close relation with the industry.

Patterns of needs integration and learning

Norway has extensive resources, but very low support for wind power, reflecting perhaps, low societal needs for renewables in a system with close to 100% renewable electricity. Early initiatives in Norway were partnered with Dutch companies under the Dutch certificate scheme in the 1990s. There were high expectancies to wind during the planned ascension to the Swedish certificate scheme. However, the incoming left-socialist-centre government, in 2006 turned to a feed-in system with Europe's lowest feed-in tariffs. The Norwegian feed in system provide 8 øre, or less than a Eurocent pr kWh for wind power (Stortingsmelding nr 11, 2006-2007).

ENOVA has since 2001 given economical support to 10 wind power farms that producing about 1,4 TWh. This has left a deficit of 1,6TWh for Government to reach its goal on 3 TWh in 2010. ENOVA has just recently opened up for support to build more wind power farms. Innovation Norway is also contributing to support Norwegian wind power through the programme "Wind and Ocean" aimed at strengthening the companies' ability to enter the international market through competence, market knowledge and networks.

Offshore wind

With strong engagement also from the powerful Norwegian offshore segment, the industrial mobilisation to involve policy-makers and R&D support institutions is stronger than for onshore wind. Offshore wind power allows Norway to couple its petroleum offshore competencies with electricity generation. Even though it may be a late comer in the turbine market, Norwegian offshore industry would be well positioned to develop foundation and service systems.

Development of offshore wind power may interface constructively with the electrification of offshore oil- and gas installations which thereby becomes an important element in the development of a Norwegian market for offshore wind on deep water. Cables that are provided to connect the platforms to the onshore grid may be important points of connection for future wind parks, furthermore future wind energy parks may be connected to oil platforms as part of local power supply to reduce CO2 emissions.

R&D activities associated with offshore wind power will also potentially provide a basis for other ocean energy, like wave-, tidal- and salinity power, as there will be similar challenges related to mapping of resources, regulation and basic competencies.

Resulting picture

Norway has large areas with strong wind. The theoretical potential for onshore wind power is 1165 TWh per year (NVE, 2003). This includes all regions with an average wind speed over 6m/s, covering 26559 square kilometres or 8,7% of Norway's area (SSB, 2004).

Compared to the resource potential, the Norwegian engagement in wind power has been very limited. The installed capacity today provides around 1 TWh wind power, and the authorities have a goal to increase this to around 3 TWh in 2010 (Stortingsmelding nr 29, 1998-99) which is not much, but even so the government is going to have problem reaching that goal. There are extensive plans for wind power, and NVE has estimated that about 15 TWh wind power may be fed into existing power grids. The combination of large wind power resources, and access to flexible load management through its hydropower system with large storage capacity is also a clear asset for the Norwegian wind power.

Offshore wind power has recently been emphasised as an interesting field for development in Norway. Internationally about 1000 MW offshore wind-power has been installed in shallow water. In Norway there are notified plans with concession applications pending for establishment of wind power in shallow waters close to the coast, but no projects have so far been implemented. In a more long term perspective, there is a focus on enormous potentials. In a recent study by the NVE and Enova, the potential for offshore wind power near land and at depths of under 50 m is in the magnitude of 200 TWh per year. Studies undertaken for Enova (2007a) shows that the potential at sea, more than 20 km/sec from shore, is in the magnitude of 14 000 TWh per year.

4.6 Small Scale Hydropower

Actors
Since large scale hydropower has become more or less politically unacceptable over the last 10-20 years, there has been extensive development of new mini- and micro power stations with an installation of less than 1 MW. As of January 1st 2007, 357 small scale hydro power stations were constructed, with a total generator capacity of 430 GWh. The actors involved in construction of mini- and micro hydropower are typically local proprietors, farmers and others who see opportunities for additional income. There has been considerable growth of suppliers, which today count around 20. Companies like Norsk Grønnkraft AS and Småkraft AS, Statkraft are important actors for construction and operation of small hydropower. The supply side, involving delivery of turbines, generators, control systems, valves etc counts actors like Voith Siemens, Vatech Møller, BN Turbin, Spetalen AS og Small Turbine Partner AS, Ahlsell Norge AS, Alstom Norway AS, Bevi Norge AS / BEVI Teknik & Service AB, Bygland Teknologi Vannkraft, Energi Teknikk AS, Fred. Olsen Renewables, GE Energy Norway AS, Industri Link AS, MiniHydro AS, Minikraft A/S, MultiControl AS, Ryfylke Elektro AS, Sønnico Installasjon AS and Teksal Hineco AS (Småkraft foreningen, 2008).

Patterns of needs integration and learning
Small scale hydropower is supported by R&D from the department of Hydraulic and Environmental Engineering at The Norwegian University of Science and Technology (NTNU), which has most of the research and development for small hydropower in Norway based on their control laboratory for turbines. This laboratory is financially supported by the Norwegian Water Resources and Energy Directorate (NVE).

However, there has been little or no R&D on the planning and environmental consequences of small scale hydropower. According to the regulatory authorities, there is a need for development of well functioning intake, with low maintenance costs, as well as for developing environmentally friendly technical solutions to reduce the construction costs. Furthermore, the total effects of many mini and micro power works in a region calls for better regional planning and follow-up

Resulting picture
The Norwegian potential in for mini and micro power stations is around 25 TWh at a price of less than 3 kr/KWh (NVE, 2004). Small scale hydro power is actively supported by the Ministry of Petroleum and Energy in order to increase the availability of electricity, value creation in Norway and support livelihood for the districts. Furthermore introduction of new energy legislation has made it easier to get grid access for independent electricity producers. Higher and more stable electricity prices and considerable technology development has also lead to a larger interest in building small scale hydro power stations the latter years.

4.7 Concluding reflections – Norwegian energy innovation system

Norway has successfully developed a resource-based economy, where energy is the core component. The OECD, in its 2007 review (OECD 2007) praises the country for sound macroeconomic management and steady growth, as well as innovation driven positioning in the world market of products, many of which are energy related.

However, more specific OECD studies of the Norwegian innovation system have not been equally positive. In a contribution to the OECD MONIT project, Remøe and the NIFU STEP institute (2004) argue that there is a weak link between economic policy and innovation policy, leading to a weak strategic framework for innovation policy, where long term mechanisms have weak foundations.

The weakness pointed out by Remøe has not affected all Norwegian energy sectors equally. Given its predominantly corporate funded innovation system, the petroleum sector has been able to sustain long term oriented innovation strategies with high resource input. This system was spearheaded by the national oil companies Statoil and Norsk Hydro, but foreign operators have also invested significantly in petroleum related R&D. Even if the outsourcing of oil and gas R&D from the oil industry to the supplier industry has led to an increase in the outsourcing of R&D tasks to research milieus abroad (Mikkelsen 2004), this innovation system is still strong.

Relative to the petroleum innovation system, the renewable innovation systems in Norway are weak. As pointed out by Midttun and Koefoed (2005), Norway does not stand out with remarkable renewables policies in a Nordic perspective. The hydropower sector, which expanded extensively until the late 1980s, has built down its innovation system following deregulation, and political blockage of continued large scale hydropower construction. The remarkable Norwegian photovoltaics engagement, therefore, is primarily export driven, and comes out of innovation and industrial transformation systems in the electrometallurgical industry.

Energi 21, (2007a,b,c) marks a broader engagement for strategic innovation in renewables, and has come up with impressive overviews and visions. It still remains to be seen how these visions get coupled to operative policies, however. Norwegian renewable energy support systems are falling behind their European neighbours' and a major lift in operative financing needs to be made to see the energi 21 visions come real.

The engagement of the North sea petroleum cluster in offshore wind (Energy council working group (2008) represents an interesting development. They carry the sign of large scale international ”petroleum thinking”, and if they are lifted into practice, they may contribute substantially. However, successful implementation of this strategy presupposes major deregulation of currently nationally segmented European renewables markets.

5. Renewable energy innovation systems in Finland

5.1 Introduction

Surprisingly few studies of the energy area in Finland seen in an innovation system perspective exist. Among the exceptions are studies in the bio energy area and on hydrogen. As the existing literature on energy innovation systems in Finland is limited, this section builds to a large degree on other types of sources, e.g. other kinds of analysis reports and overview descriptions, strategies or policy descriptions by actors connected to the field. In addition, personal communication with a limited number of experienced experts has been carried out. The section thus has another character than the previous chapters and does not give a full picture of all relevant aspects in the energy innovation systems.

While Finland is famous for its well-functioning innovation system in general, there has in Finland been relatively little attention to the energy area as an area of innovation. Instead, the energy area is considered an important basic, supporting element in the general Finnish innovation system. The characteristics of the Finnish energy area are prerequisites for the well-functioning general innovation system (OECD 2005).

Energy is primarily seen as a basis commodity and infrastructure of society. Energy is a central production factor and the availability of energy at reasonable prices enables economic growth and employment. Also for households and societal functioning and welfare, energy is important. [25] A secure and robust energy supply is the primary objective in the energy policy and strategy of Finland (MTI 2005 and 1997). Secondly, the policy is to support the development of markets for energy, to ensure low costs and to be integrated in the international markets and EU developments in the field. Thirdly, efficiency in energy production and energy use and energy conservation are aimed at in order to limit the long-term growth in energy consumption. Finally, sustainable development, environmental and climate protection are an overall objective. This includes promotion of use of renewable energy.

Diversity in the energy sources, a degree of decentralized energy production, and connections abroad are elements that shall support the robustness and security in the energy supply. The energy use in Finland stems from a multitude of sources, fossil fuels, renewables as well as nuclear power.

There is a considerable degree of integration between energy consuming industries and the energy supply in Finland. The energy-intensive industries like the pulp and paper industry, the wood industry, the basic metal industry, and chemical industry are influential actors in the Finnish energy sector. They have a large say, not only as consumers of around 50% of the energy, but also as producers of energy. Considerable parts of the energy area are thus integrated with the industrial companies and industry-owned energy companies are common in Finland.

The energy systems in Finland have historically been connected to the local or regional level rather than a general national level. This is still the case. The tradition of organising in local co-operatives and a pronounced emphasis on independency and self-sufficiency in local municipalities are characteristic. Rather than centralised top-down planning from national level, there is tradition for a consensus-oriented dialogue between actors at national and local level. This ensures and enables the variety and diversity in the energy systems (Christiansen & Tangen 1999).

Finland has considerable exports of energy technology. While the import of energy technology earlier was larger than the export, the balance changed during the 1990s to a considerable export surplus (Monni et.al. 2002). However the increase in exports of energy technology has in the period 2000-2005 not been larger than the general increase in exports (see Figure 4).

[25] Personal communication with Eva Heiskanen NCRC, Raimo Lovio, HSE, Per Lund, HUT

5.2 Biomassed based CHP and gasified biomass[26]

Actors and networks

As in Sweden, biomass has central position in the energy system in terms of heat supply, but unlike Sweden, Finland was a front runner in terms of power production from biomass. Another central feature of the bioenergy innovation system in Finland is a well-developed machine industry. Virtually any component in combined heat and power plants (CHP) (apart from turbines) is available from Finnish producers, e.g. boilers, heat exchangers valves, piping, instrumentation etc. and is produced for exports too (Christiansen & Tangen, 1999).

As in Sweden, there is also a strong academic cum institute knowledge base in combustion and gasification as well as strong networks between VTT and industry (e.g. Kurkela, 2008, Salo, 2008). The knowledge base was early diversified into gasification of solid biomass and a world leading application in CHP was built in early 1990's in Värnamo in Sweden by the Finnish paper and pulp manufacturer Ahlström (later acquired by Foster Wheeler). Another firm, Tampella, was also involved in early investments. These two pioneering firms have (although under new ownerships) been able to keep the knowledge base in solid fuel (and waste) gasification (Salonen, 2008; Salo, 2008). An additional strong knowledge base in gasification lies in VTT and in parts of academia (Kurkela, 2008, Fogelholm, 2008). This knowledge base has survived in part though government funding of R&D but also by the occasional commercial projects (e.g. one in Lahtis and one in Skive, Denmark).

Hence, the Finnish machinery cluster related to biomass CHP and gasification has been strong for some time. Indeed, it appears to have been strengthened recently (partly mirrored by a weakening of the Swedish cluster). First, Metso (a firm on the top ten list in Finland) recently bought Kvaerner Pulping and in that deal, Kvaerner Power (located in Göteborg and a leader in biomass boilers) was included. Second, the Austrian paper and pulp machinery firm Andritz recently invested in the cluster. It is diversifying into power equipment, acquired the smaller Finnish firm Carbona (specialized in gasification technology) and has located its activities in the small town of Varkhaus where also Foster Wheeler is located (Kurkela, 2008).

Patterns of need integration

As in Sweden, the extensive district heating system and the large paper and pulp industry are basic structural factors driving a needs integration. The huge forest based industrial structure has generated well developed supply chains and cheap raw materials in terms of waste wood and waste from industrial processes. In Finland, an additional factor has been a shortage of alternative power sources, in particular in relation to Sweden, much less hydro power and a smaller nuclear power capacity. Biomass has, therefore, always been of high priority in Finland (Fogelholm, 2008). This has also been reflected in large government funded R&D programmes supporting that sector (Fogelholm, 2008). Public policy and environmental regulation have been of considerable influence to energy-related innovations in the pulp and paper industry (Kivimaa et.al. 2008).

There are a considerable amount of connections to other countries in the bioenergy area, not least to the neighbour countries. To some degree, the bio energy area can between Finland and Sweden be considered a partly common innovation system with extensive interaction and collaboration across the border, with a common integration with the wood industry, the pulp and paper industry, and with instances of joint R&D programmes between the countries.

Effects of the patterns of needs integration and key policy challenges

With a very strong industrial cluster in boilers and in paper and pulp machinery, Finland is in a very good position to exploit the growing market for conventional biomass heat and power technologies. As importantly, the Finnish cluster is very well positioned to gain much from the very large market for gasified biomass (for transport fuel) that has suddenly come into sight due to the new EU proposition of a 10% share of biofuel in the EU by 2020 (Salonen, 2008). Unlike in Sweden, the Finnish companies currently exclude black liquor gasification (Leppalahti, 2008). Instead, they are searching for opportunities in solid fuel gasification and envisage building bio-combinates where production units for biofuel are co-located with the paper and pulp factories. There are currently two industrial consortia exploring such opportunities.

[26] This section draws heavily on Hellsmark, in progress.

These consortia include not only suppliers of gasification equipment but also major Finnish companies such as UPM, Stora Enso and Nesté Oil (Kurkela, 2008). Hence, the very strong historical trajectory in biomass is currently being extended by a mobilisation into gasification and this mobilisation involves major industrial companies in Finland.

5.3 Hydrogen and fuel cells

Actors
The Technical Research Centre of Finland (VTT), the Helsinki University if Technology (TKK), and Tampere University of Technology, Institute of Material Science are the leading research organisations involved in R&D related to hydrogen and fuel cells in Finland. Also other universities have activities in Hydrogen and fuel cell technology: University of Jyväskylä. University of Helsinki and Åbo University.

The key public sponsor of hydrogen and fuel cell related R&D in Finland is TEKES, the Finnish Funding Agency for Technology and Innovation. TEKES has funded R&D related to H2FC since 1995 and focus has been on distributed hydrogen related energy systems and R&D affiliated with low temperature fuel cells (PEM, AFC and DMFC) (IEA, 2004). TEKES has jointly with industry and VTT funded research in fuel cells with approximately 6 M€ annually within recent years.

Finnish Chemicals Oy is a large producer of hydrogen (5000 t/year) to industrial use in process industries. Also Woikoski, a Finnish producer of industrial gasses, has since 1913 produced hydrogen. Apart from this, few industrial actors have presently market oriented activities in hydrogen technologies but Finnish industry is increasingly active in fuel cells. Several of the large Finnish industrial actors have shown interest in applying fuel cell technology in their established products.

Large firms as Patria Vehicles (defence industry and armoured vehicles) and Kalmar Industries (e.g. fork lift trucks for container handling) are considering fuel cell based systems. Other technology firms such as KoneCranes, Outotec (formerly Outokompu Technology), SALCOMP (mobile phone chargers) and Sandvik Mining and Construction Oy and energy trade and distribution firms as GASUM and NESTE OIL have shown interest in the technology.

Within fuel cell technology and equipment manufacturing a couple of new firms have been established. Hydrocell is a developer and producer of fuel cells and PEM-Energy was established in 1998 and aims to be a supplier of commercial stationary power units (in the range of ½kW to 10kW) based on PEM Fuel cell technology. Hydrocell also has metal hydride storage units for hydrogen in its product programme. Wärtsilä Corporation is close to having a commercially available stationary CHP and APU based on SOFC fuel cells from the Danish firm Haldor Topsøe Fuel Cells. A 20kWe alpha-prototype has been in operation since October 2007 and in the summer of 2008 a similar unit was inaugurated by Finland's Minister of Trade and Industry, Mauri Pekkarinen, at a Housing Fair in the city of Vaasa. The Vaasa plant is fuelled by methane gas from a nearby landfill (Wärtsilä 2007, 2008).

To this can be added firms specialised in components for fuel cells power systems such as MSC Electronics (power converters), Perlos (packaging and electro-mechanical parts for small fuel cells) and Verteco Ltd. (power electronics).

The above mentioned firms are all affiliated with the use of hydrogen or fuel cell technology in stationary and transport (niche) applications. Mobile applications of fuel cells have earlier been investigated by NOKIA, but no commercial product is yet available from the large Finnish mobile phone manufacturer.

Patterns of needs integration and learning
As mentioned TEKES has sponsored hydrogen and fuel cell R&D since 1995. TEKES has sponsored three larger activities. One activity has been focuses on low temperature fuel cells (PEM, AFC and DMFC). Another activity is the 'FINSOFC 2002-2006 Business for Finnish Companies'. In these two programmes a large number of key Finnish industrial actors and research organisation cooperated. A third activity is DENSY (Distributed Energy Systems) programme which from 2003 to 2007 had a total budget of near 60 M€. During this program TEKES financed 123 enterprise and research projects in developing distributed energy systems. A part of these research projects were hydrogen and fuel cell related (TEKES 2007a).

In 2006 TEKES sponsored the development of a 'National fuel cell development strategy Proposal'. This strategy was directed by steering committee primarily with industrial representation. As a result TEKES launched a Fuel Cell Technology Programme 2007-2012 with the aim to exploit and commercialise fuel cell technology. The programme has a total volume of 150 MM€ over the period with a direct TEKES contribution of 50 M€. The programme has four elements. 1) Joint industry oriented R&D projects between industry and R&D institutions as well as promotional and educational activities; 2) Institutional cooperation and networking; 3) Actual cooperation and networking on R&D and industrial cooperation; 4) Domestic demonstration projects (TEKES 2006).

A key driver in the Finnish fuel cell innovation system is 'Fuel Cell Finland Industry Group' that was formed January 2006 as one of the recommendations in the strategy plan. The purpose of the grouping is to intensity the co-operation among the Finnish industrial companies and other stakeholders.

Another vehicle of integration of needs between industry and research is the Äetsä Hydrogen Village. It acts as a platform for interaction (boundary surface) between equipment manufacturers and research institutes by providing its stakeholders with laboratory support and full scale testing facilities. The laboratory and an affiliated information centre are sited at the premises of Finnish Chemicals Oy in the town of Äetsä. Administrative support is provided by Prizztech, a member of the Finnish Science Park Association and with the primary task to enhance enterprise competitiveness in region of Satakunta.

Finnish actors are reported to have a considerable activity in international R&D programmes (IEA, 2004).

Resulting picture

There seems to be some integration of needs in this formative phase of a Finnish innovation system on fuel cells. With TEKES in a proactive role industry led R&D and demonstration programmes are outlined with learning as a key element. The needs of the domestic energy markets seems less integrated in the ongoing activities, but hydrogen and fuel cell technologies are still years from seriously impacting energy systems anywhere in the World.

5.4 Wind energy

Actors

A main group of actors in the wind energy area in Finland are around 10-20 manufacturing companies within the country's well-developed machine industry. The companies have gained a role as important suppliers of components to wind turbines (Vehmas & Luukkanen 2005, p. 106). Among the products are key components like generators, gearboxes, bearings and drives. Considerable exports stem from the production of components. In addition to this, a couple of manufacturers of wind turbines exist, however with relatively small-scale production only. The turnover in the wind-industrial sector is around 270 million euro (2005 figure; estimated to over 300 million euro in 2006) (IEA 2007b).

The wind area is considered by national policy actors as well as by actors on local level in some regions. A number of larger and smaller energy companies have wind power units, primarily in the coastal areas. The share of wind energy in the total electricity production is however little, less than 0.3%, and the growth in capacity has been among the slowest in Europe (Nordel 2007, Vehmas & Luukkanen 2005). A limited number of turbine retailers, project planners, and companies offering maintenance and other service in connection to wind energy exist.

The Finnish Association for Nature Conservation and other environmental NGOs are, like on other renewable energy areas, active in supporting wind energy. FANC has established a certification system for wind electricity and other green electricity.

Patterns of needs integration and learning

The processes of needs integration and learning in connection to the Finnish wind energy area to a considerable extent occur in the supply chain networks of the industrial companies. The interaction between sub-suppliers and manufacturers of wind turbines about the different components is a central locus for the knowledge development.

The networks between sub-suppliers and manufacturers are often international. There are for example important connections to the wind energy industries in Germany, Denmark and the Netherlands. There are also connections to actors in India and East Asian countries and some of the companies are (co-) owned by Asian actors. The large wind turbines delivered by Finnish manufacturers are based on German turbine technology and design (Enertec 2006).

With the growing maturity of the area in the recent years, the interaction between sub-suppliers and manufacturers has been systematised to a larger extent than earlier. The also concern the innovative dialogue concerning improvements and possible radical changes in the products in the longer rum. In many cases, the partners establish forums and define time specifically for this purpose. Thereby they among other things can explicate what knowledge development, research and experiments that are needed for the further developments. Apart from between manufacturers and component suppliers, some of the larger suppliers that are delivering a number of different component from different company units, have also internally organised the discussion of further innovation in components and in the wind technology in general. A company like ABB, that produces e.g. gears for wind systems in Finland, cables in Sweden, a third product in Switzerland, a fourth in Denmark, etc., has established a wind-focused organisation within the larger, general organisation. This connects the different units of the company that works with wind energy, and thereby enables a systematic dialogue between the units about the future developments and potentials (Rasmussen 2008).

The component suppliers in Finland have moreover established a wind technology branch group under the general industry association in the machine area ('Technology Industries in Finland') (IEA 2007, p. 118).

Wind energy plays only a little role in the Finnish energy systems and it is fair to say that Finland does not have a strong domestic market for wind turbines. The installed capacity is much smaller than in Norway, Sweden and Denmark. The learning from actual domestic application is therefore not very extensive in general, though experiences with planning and operation of wind-power units have been gained from a number of instances. There are fair wind resources in some of the coastal and arctic regions, though they are not as large as on the west coasts of Norway, Sweden and Denmark.

Integration of specific needs and performance demands have appeared in some instances in Finland from specific types of application. For example the learning from the arctic area has lead to technology for ice prevention on the blades of windmills.

Wind energy is one of the means of increasing renewable energy (also other than bioenergy) in the Finnish energy systems. The national energy policy has supported and directed attention to the wind energy. Wind energy is among the elements that can contribute to the intentions about an energy system building on a diversity of sources and increased share of renewable energy in general. For a number of years, the instrument of investment subsidies for renewables has been employed. The support for wind energy is 40% of accepted costs (while 30% for other renewables) and thus a considerable share of the total costs of the wind power systems is covered by this. In total and absolute numbers the investment subsidies to wind energy have however been much smaller than to bioenergy, as less wind power capacity has been installed despite the support (Vehmas & Luukkanen 2005).

The efforts of supporting market application seem only to have been limited successes and they have not ensured a large learning from market applications. Also the certification systems and labels of green electricity have been established are of modest success. Only a few percent of the household consumers have used the opportunity of changing supplier of electricity (IEA 2007 p. 121).

Like on other renewable energy areas, the awareness of wind energy is high in Finland. A majority of the population is positive to the area and finds that wind energy is the most important form of energy to increase the use of in electricity generation. However there is also a relatively large share that sees both pros and cons in wind energy. (Eurobarometer 2007, see Appendix, and FEI 2007). Among the reservations is the visual influence on the landscape e.g. in holiday areas and on the coast. This experience is taken up by the planning authorities, among other things by defining new area of possible location of wind power plants off-shore at a longer distance from the coast.

Research on wind energy occurs though it, measured by amount of programme funding, is among the smaller areas of energy research. The research subjects are among other things grid integration, short-term forecast models, and fauna impacts. Apart from in the energy related R&D programmes like the DENSY programme (Distributed Energy Systems), the SCT programme (Sustainable Community Technology), and earlier (until 1999) in specific wind programmes, there has also been a number of research projects in machine-oriented programmes, like the Smart Machine programme, dealing with components for wind turbines (IEA 2007). The projects are usually closely connected to industrial companies.

5.5 Solar cells

The installed solar cell capacity in Finland is 4,1 MW (IEA/OECD 2007). This is an increase on more than 50% since year 2000. The solar cells area does not appear as an integrated part of the general energy systems in Finland. Instead it has a role in niches of remote and off-grid small-scale electricity production for individual purposes. The innovation system with respect to solar cells is thus relatively independent from most of the major actors in the energy area in Finland.

The use of solar cells appears in the considerable amount of holiday cabins that have solar cells integrated in roofs and facades. Moreover, solar cells are integrated in navigation aid systems around in the country. An account in 2002 found that around 40000 holiday cabins and 2000 navigation aid systems had solar cells (Alakangas 2002, p. 45 and Appendix B).

The solar cell innovation system in Finland is fragmented and with scattered activities (Skarp 2008). NAPS (Neste Advanced Power System) provides solar cells systems for projects abroad and in Finland. The company, that has background in material-chemistry research, is primarily retailer but has some own module manufacturing through Arctic Solar in Sweden. Though attempts to start up production of thin-film cells and c-Si have been made, industrial manufacturing of cells or modules are not established in Finland.

In addition to NAPS around ten retailers and suppliers of components and know-how exist. These are amongst others Okmetic (know-how on single crystal silicon manufacturing), LUVATA (supplier of copper ribbons used in connectors), Braggone (supplier of ARC materials) and Beneq (large area ALD equipment). Arrivac is one of the consultancy companies working with solar cell systems, while the company Endeas provide solar simulators. Research is carried out primarily on dye sensitized solar cells in TKK (Helsinki) and on organic solar cells in TTKK (Tampere). The number of projects on solar cells under the public R&D programmes is very limited (see table below and Appendix B). Most of the delivered solar cell systems in Finland go to export (70%), among other things through development aid projects in developing countries.

Like in Denmark and Sweden, the solar cells area in Finland is more likely to be a follower than a leader to the international development of the solar cell technology in general. The learning and need integration through home market application and application-near experimentations have not been developed to a larger extent. The degree of positive external economy is limited and the supporting knowledge areas of different kinds that are crucial for the further development have only been mobilised to a limited extent.

The formation of market dynamics in the Nordic countries has not been strong enough and too slow and unfocused in order to support the solar cell developments. Though there has been support to solar cells area through the public research and innovation programmes, the support has a scattered and fluctuating character and does not cover broadly.

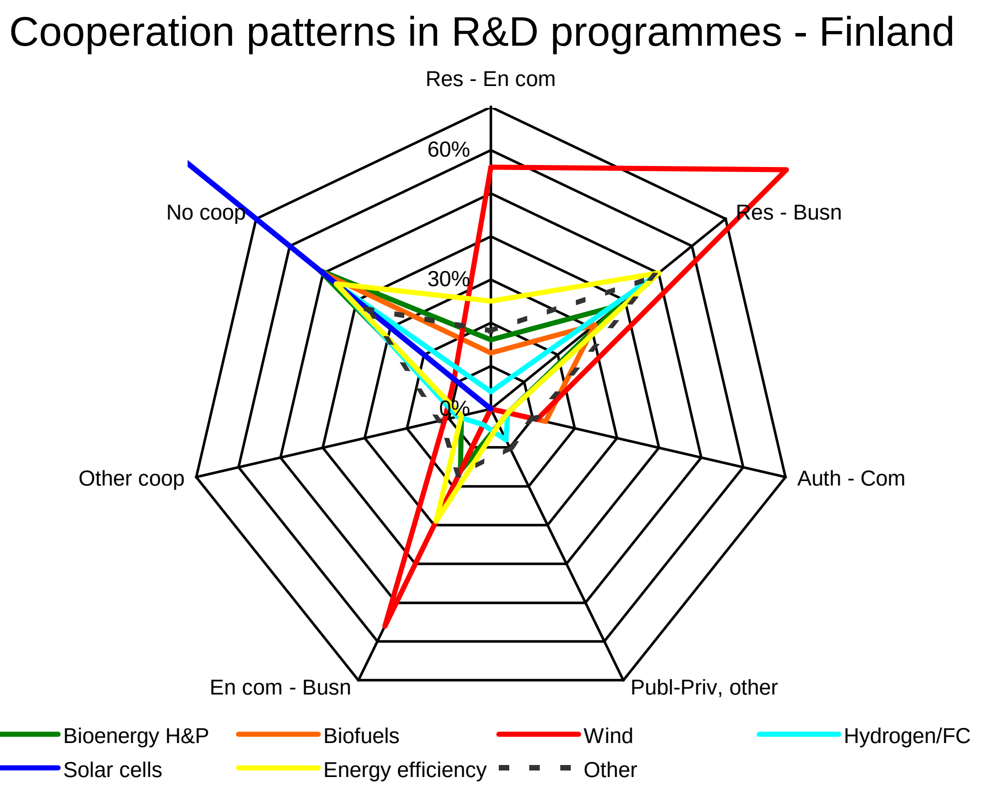
The activities on solar cells in the Nordic countries to a large extent have character of niche roles in the general international developments. Among the niches are semiconductor materials and power electronics. There has in Finland been a degree of experience with building integration of solar cells, specifically in holiday cabins. In many other countries, the building integration is a dimension that has been under-represented in the solar cells activities so far. With for example inclusion in architectural and engineering educations, there are made efforts for changing this. A stronger anchoring in the building and construction industries in the countries is also needed.

Cooperation patterns in public R&D programmes

The analysis of cooperation in the public energy R&D programmes shows that there is a considerable amount of cooperation across actor types in the projects of the programmes, though the cooperation pattern is not quite as broad as we have seen it in Norway and Denmark.

In almost half of the projects, there is cooperation between research institutions and business companies. This is the highest share in the Nordic countries. The wind energy area stands out with even 88% of projects with this type of cooperation (and cooperation between energy companies and research institutions in more than half of the projects).

There is no cross-going cooperation in 42% of the projects. In the bioenergy area alone the share is around 50%.



Finland – Actors in national R&D programmes (number of projects).

	Energy companies	Business companies (other)	Research	Authorities	Other	Total N
Bioenergy - H&P	20%	51%	91%	7%	4%	45
Biofuel – transport	25%	44%	88%	19%	0	16
Wind energy	56%	89%	100%	11%	0	9
Hydrogen & fuel cells	4%	83%	67%	8%	8%	24
Solar cells	0	0	100%	0	0	2
Energy efficiency	29%	64%	86%	0	4%	28
Other	18%	63%	82%	18%	9%	78
Total	20%	62%	84%	11%	6%	202

In general there are relatively few projects with interest organisations etc. involved (the category 'other' actors) compared to the situation in Norway, Sweden and Denmark. The share of projects with research institutions involved is higher than in these other countries; more than 80% the projects.

5.6 Concluding reflections – Finnish energy innovation system

The energy innovation system in Finland is significantly influenced by the well-developed and internationally oriented machine industry in the country. To a large degree the machine industry has cluster character with extensive learning activities, networks, and synergies from a multitude of activities. The strong competences of the machine industry are reflected and further developed in the energy area. This shows both in the bioenergy area and the wind energy area as well as in other technology areas as for example combined heat and power in general. The machine industry constitutes a main basis in the Finnish energy innovation systems.

The use of public R&D programmes as a governance instrument in Finnish energy development is systematised and routinized to a considerable extent in Finland, primarily in the institutional context of TEKES and in Academy of Finland. A large business participation in the programme activities is ensured as many programmes are targeted and weighted towards business actors and designed with requirement of clear business participation. Other actor types are usually not to the same extent systematically prioritised in the programmes.

With a running period of typically around 4-6 years, the programmes are as policy instrument more flexible than permanent programmes, still long enough to enable some degree of continuity. This is moreover supported by programme structures that often are similar or identical from one programme to another. In addition some programmes are continued with a second (and third) period after the first. Typically an adjustment of the purpose and goals of the programme will take place when a new period is decided upon. The programmes constitute a platform for need integration between market-knowledgeable actors and developers and researcher.

Concerning renewable energy technologies and sustainability, bioenergy accounts for a large share of the activities within the programmes in general. This is naturally so; however it also seems important not to fall in the trap that says that sustainable and renewable energy is identical to bioenergy only. This will not ensure a degree of competition between different technology areas. Moreover it is important to look at also other parts of the energy systems than the energy production side only.

While the energy area as mentioned is not considered primarily an area of innovation in Finland, but a commodity and societal good, there has in the closely related field of environmental technology and sustainable development, that has received increasing attention in the latest years, been considerable emphasis of innovation perspectives. This e.g. shows in national policies, the strategy for sustainability, clean tech investment investigations, and in the public R&D programmes on climate and environmental issues, that have considerable emphasis on business. This development tendency will most likely also be of influence to the energy area in the coming years.

6. Renewable energy innovation systems in Iceland

6.1 Introduction

Very little analytical literature exists about the energy innovation system in Iceland. Therefore this chapter cannot be seen as a full, systematic description of the innovation system, but as a row of observations building on a limited selection of other types of written material and in a few cases supplemented with personal communication with involved actors. The activities on solar cells, wind energy, and bioenergy are very limited in Iceland, but instead observations on geothermal energy are included.

Iceland has very large domestic energy resources in the form of geothermal energy and hydropower. The Government estimates that the total exploitable potential is annually 30 TWh from hydropower and 20 TWh from geothermal sources. This means that it is only between 20 and 25 % of these domestic renewable sources that are yet being harnessed. The exploitation of these resources is an important issue in Iceland's industry policy.

Energy consumption per capita in Iceland is among the highest in the world. The primary energy sources are domestic geothermal and hydro power and imported oil and bit of coal. Most of the oil consumed in Iceland is used in the fishing and transportation sectors. 71% of Iceland's total energy consumption stems from geothermal and hydropower (Orkustofnun 2006).

The majority of the country's electricity (70%) is generated using hydropower; the remainder 30 % is based on geothermal sources (Nordel 2007). About 90% of all housing in the country is heated with geothermal energy; the remainder being heated mainly with electricity.

Because of the abundance of relative cheap electricity Iceland has attracted energy intensive industries (i.e. aluminium smelters) and industry accounts for 78% of the electricity consumption. The electricity production was 8.7 TWh in 2005 and it is expected to increase to 14.6 TWh (a 70% increase) in 2008 due to increased need in the aluminium industry.

The Icelandic industry is dominated by activities related to fishing, and the fishing industry has been the stable element in the Icelandic economy for decades. But with the increased variation in fish catching Iceland has with an active research and innovation policy over the latest decades broadened its' industrial structure (Gergils 2006). As a consequence the total R&D expenditure in Icleand (both public and private) has been increased considerably from a level of a little more than 1% of GDP in mid 1980's to 2.8% (4 bn ISK, 24 M€) of GDP in 2005. Today Iceland has the fifth highest R&D expenditure per capita within the OECD. Private and public expenditures accounted each for approximately half of the total. Iceland's energy R&D apparently has not been increased in the same pace. Energy R&D accounts for approximately 3% (in 2005) of the total (Rannis 2007).

The governance of Iceland's innovation system was reorganized in 2003. With a great deal of inspiration from Finland the Icelandic innovation policy aims to strengthen university-based research, restructure the public research institutes, improve support to business innovation and entrepreneurship, and increase education in science and technology (Dannemand Andersen, et.al. 2007).

Iceland has three large actors funding energy related R&D. RANNÍS (the Icelandic Centre for Research) is the key public actor in Iceland's innovation system. For the Ministry of Education, Science and Culture RANNÍS administers key funding for research and education such as the Research Fund, the Instrument Fund, and the Graduate Training Fund. For the Ministry of Industry and Commerce RANNÍS administers the Technology Development Fund.

Orkustofnun, the National Energy Authority, is another key actor in Iceland's energy innovation system. Orkustofnun is among other tasks responsible for through the National Energy Fund to support growth in the use of domestic energy resources. The fond initially focused on electrification of rural areas of the country, but has recently primarily set focus on funding basic energy/electricity research and geothermal heat exploration. Together with all universities in the Reykjavik area, Orkustofnun is funding and operating the National Energy Fund, with the aim of enhancing research in the fields of the environment and energy. The universities are: University of Iceland, Reykjavík University, Iceland Academy of the Arts, The Iceland

University of Education, The Agricultural University of Iceland, Bifröst School of Business and The United Nations University Geothermal Training Programme.

Finally, Orkuveita Reykjavíkur (OR) or Reykjavik Energy is the largest utility provider for the Reykjavik metropolitan area and the company extends its services to 67% of the Icelandic population. OR provide electricity, hot water for heating and cold water for consumption. OR and the universities in the Reykjavik area have established the autonomous research fund 'The Environmental and Energy Research Fund'.

The University of Iceland and The University of Akureyri cooperate on offering an intensive one-year MSc Programme in Renewable Energy Science. In 2008 the school will focus on three specialisations of study: Geothermal Energy, Fuel Cell Systems & Technology and Biofuels & Bioenergy.

6.2 Hydrogen

Actors

As a energy resource rich nation without fossil fuels for the transport sector the prospects of replacing imported fossil fuels by domestically produced hydrogen or hydrogen based fuels (like methanol) has been discussed in Iceland at least since the 1970s. Since 1999 the has been a political goal of the Government of Iceland to promote increased utilisation of renewable energy sources and utilise renewable energy in (for example in form of hydrogen) as a fuel for powering vehicles and fishing vessels (Árnason & Sigfússon 2000). There seems to be a political consensus to try to transform the energy system of Iceland into a hydrogen economy in the time range of 2030-2040.

University of Iceland in Reykjavik has since the 1970s been a key academic actor within hydrogen. Especially, two professors (Bragi Árnason and Thorsteinn I. Sigfússon) of the University of Iceland have brought the Icelandic discussions on the hydrogen society into an international arena. The University of Akureyri is to a lesser extent involved in hydrogen related research.

IceTec, the Technological Institute of Iceland, has participated in various hydrogen research and demonstration projects.

Icelandic New Energy (Íslensk NýOrka[27]) is the country's key actor in promoting hydrogen as a fuel in the transportation sector. The majority shareholder is VistOrka, a semi-governmental entity controlled through the New Business Venture Fund, and the other shareholders are three large international actors: Daimler, Norsk Hydro and Shell Hydrogen. Most of Icelandic New Energy's (INE) projects are EU-funded. In the EU funded ECTOS-project INE opened in 2003 the world's first hydrogen filling station and three hydrogen busses were running for a three-year demonstration period in Reykjavík. INE is also involved in the follow-up EU project HyFLEET/CUTE with a series of demonstration projects.

As aluminium smelters is one of the dominating and most energy consuming industrial activities the two firms Iceland Alloys and Elkem ASA also have been involved in studies on possible production of methanol from electrolytically produced hydrogen (Árnason & Sigfússon 2000). Apart from this there are only erratic reports on larger involvement by traditional Icelandic manufacturing industry in hydrogen and fuel cell activities.

Patterns of needs integration and learning

As Iceland has a very limited industrial platform for manufacturing hydrogen and fuel cell technology and systems the most important learning perspective is related to the end-use of the technology. The most visible elements in the innovation system are demonstration activities in cooperation with international partners and science and educational activities also tightly interwoven in international collaboration.

The Icelandic government has a quite clear and coherent policy framework for stimulating the hydrogen related innovation system. The government mentions five main elements it its policy on hydrogen: 1) private public co-operation on policy formulation, 2) a generally favourable framework for business, 3)

[27] Orka is the Icelandic noun for energy or strength.

international co-operation, 4) research and 5) education and training (Icelandic Ministry of Industry and Commerce, 2003).

The hydrogen and fuel cell related innovation system of Iceland is to a high extent interacting with international industrial partners and funding organisations. As mentioned the key actor INE is half owned by leading international firms. Three experimental hydrogen driven busses from DaimlerChrysler have been operating in Reykjavik for some years. As the project were dependent on EU funding INE could not continue the demonstration beyond the termination of the EU project, but the experience gained is being used by the University of Reykjavik for further investigations. Following this a number of hydrogen driven cars from Toyota and Mercedes Benz is operated by Orkuveita Reykjavikur, the national power company Landsvirkjun, and Herz car rental firm. VistOrka intents to support at least 30 hydrogen driven cars by mid 2009 (Loftsdottir 2007). Icelandic partners are participating in many international collaboration on R&D and demonstration activities. As mentioned University of Iceland offers an MSc Programme in Renewable Energy Science with hydrogen being one of the focal technologies. University of Iceland participates in a range of European and international hydrogen and fuel cell related activities. Furthermore, University of Iceland hosts summer schools in hydrogen related science co-sponsored by Nordic Energy Research.

All three major R&D funding bodies in Iceland have launched R&D projects on hydrogen and/or fuel cells. The national Energy Fund has funded a project on exploring future possibilities of using different vehicle fuel alternatives in Iceland. The Environmental and Energy Fund has funded a market oriented study on ‘Marketing image of companies that use local alternative fuel in their services’. From the available projects lists it is striking, that relative few R&D projects on hydrogen and fuel cells have been funded taking into account the international hype related to Iceland’s move towards a hydrogen society. This also emphasises the user-end type of innovation related to hydrogen and fuel cells in Iceland.

6.3 Geothermal

Geothermal energy is a key energy source in Iceland as it provides more that half of the country’s energy supply. Geothermal sources provided almost all (90%) energy used for space heating in Iceland and 26.5 % of the electricity generation. (IEA-GIA, 2006). Governmental expenditure on geothermal R&D was approximately 1M€ in 2006. Industry Expenditure the same year is estimated to 6 – 7 M€ (IEA-GIA, 2006).

Actors

Orkustofnun operates under a special agreement with the United Nations University the United Nations University Geothermal Training Programme (UNU-GTP).

Iceland GeoSurvey (ÍSOR) is a service and research institute providing specialist services primarily in the field of geothermal research and utilisation. Today, ÍSOR is a 100% self-financed, non-profit governmental institution, and offers its key clients are the Icelandic power industry, the Icelandic government and foreign companies. ÍSOR has a staff of 80 people mostly professionals.

Patterns of needs integration and learning

As in the hydrogen and fuel cell case the geothermal related innovation system in Iceland is quite internationalised. The United Nations University Geothermal Training Programme (UNU-GTP) provides in Iceland training in geothermal resources research and utilisation to young professionals from all over the World but especially developing countries. Teachers and other expertise come from Orkustofnun, Iceland GeoSurvey, the University of Iceland, and Icelandic energy and engineering companies.

Compared to hydrogen and fuels many more R&D projects have received national funding on geothermal energy in Iceland. Several of the projects have partners from private companies and from foreign universities. The R&D projects often deals with understanding and exploiting the geothermal resources (e.g. deep drilling and numerical modelling of geothermal resources) but also with technical problems related to transfer of geothermal energy (e.g two-phase flow in pipelines).

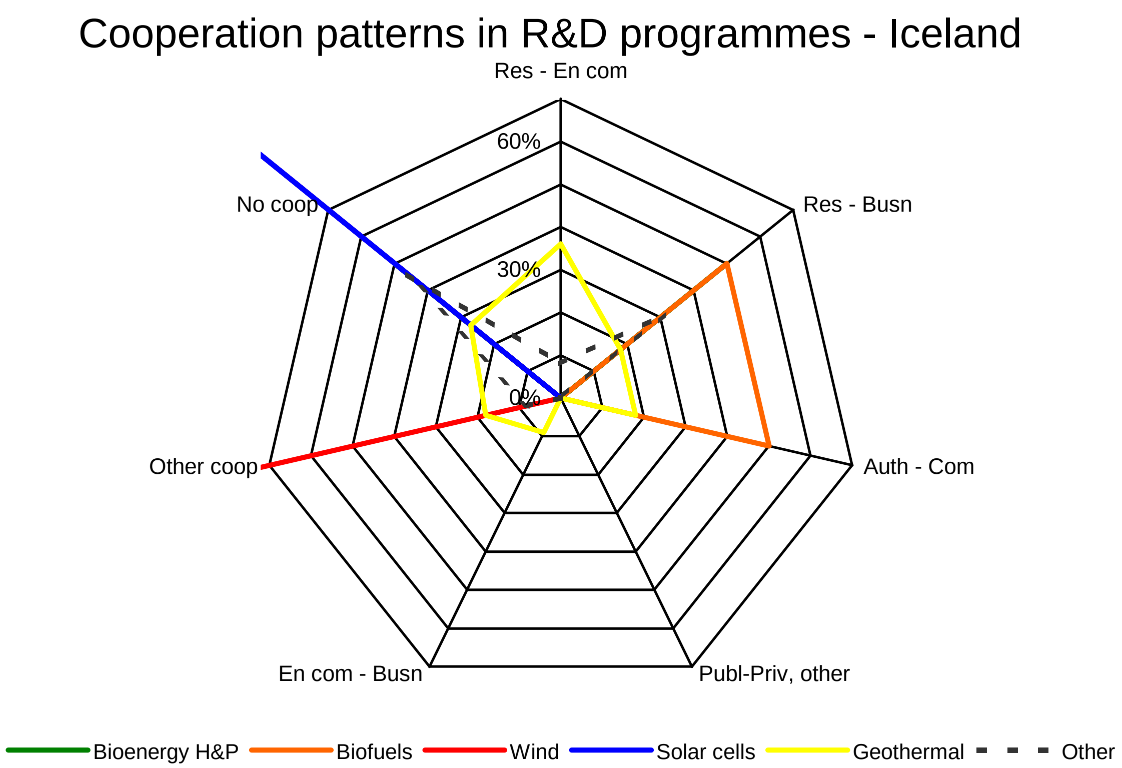
Cooperation patterns in public R&D programmes

The analysis of the cooperation patterns in the public R&D programmes show, that there is a high degree of research participation on the public R&D programmes: 87%. This is the highest share in the Nordic countries. Moreover public authorities are involved in relatively many projects, almost one fourth of the projects. The share of participation of business actors is considerably lower than in the other Nordic countries, still it is 37% of the projects. Energy companies are represented in 20% of the projects. It is interesting to notice that no observations of 'other' actors (interest organisations, NGOs, etc.) in the research and development projects were made.

Iceland – Actors in national R&D programmes (number of projects).

	Energy companies	Business companies (other)	Research	Authorities	Other	Total N
Bioenergy - H&P	0	50%	100%	0	0	2
Biofuel – transport	0	100%	50%	50%	0	2
Wind energy	0	0	100%	100%	0	1
Solar cells	0	0	100%	0	0	1
Geothermal	45%	36%	82%	27%	0	11
Other	8%	36%	92%	18%	0	13
Total	20%	37%	87%	23%	0	30

Programmes included: National Energy Fund (Orkustofnun), energy projects under RANNIS and Environmental and Energy Research Fund (Orkuveita Reykjavíkur).



In general there is cooperation across actor types in almost 2/3 of the projects in the Icelandic R&D programmes. There are a number of projects with cooperation between research institutions and energy companies and between public authorities and companies. This is the case for geothermal technology as well as for all technology areas taken together.

Geothermal technology is one of the largest areas in the programmes, judged by the number of projects. The area seems higher prioritised than the other technology areas addressed in this study, including hydrogen technology. Unfortunately it has not been possible to get sufficient information about the few hydrogen projects (four) we have identified and they are not included in the account.

6.4 Concluding reflections – Icelandic energy innovation system

The Iceland innovation system is clearly reflecting the energy systems in Iceland and the rich natural resources it is based on, not least geothermal energy and hydropower. At the same time, the innovation system is internationally oriented to a considerable degree with important connections to both sides of the Atlantic.

User-end oriented learning is important in the Icelandic innovation system. There is significant emphasis on this in development activities as well as in many research projects. The number of R&D projects and the research community are of course much smaller than in the other Nordic countries. This can justify the strong degree of research participation in the public R&D programmes. There is cooperation across actor types in around 2/3 of the projects. This is close to average of the Nordic countries taken together.

The use of R&D programmes as institutional form and policy instrument in the energy area has developed in recent years, for example in connection to the Environmental and Energy Research Fund managed by OR, Reykjavik Energy. With the openness, the systematic organisation, and the degree of competition between solutions, R&D programmes usually imply, this seems to be a promising and fruitful development for the Icelandic energy innovation system.

Another issue of central importance to the energy innovation system is the considerable development in educations on the energy area that have occurred in the recent years. The educational activities are often of international character and are including also other areas of renewable technology than those central in the Icelandic energy systems today, e.g. bioenergy. This is a good development.

7. Characteristics of Nordic energy innovation systems - lessons for policy makers

In this comparative chapter we identify a set of characteristics of the energy innovation systems in the Nordic countries. We begin with the interaction patterns within the Nordic innovation systems and then proceed to identify a number of other important features of the systems. Lessons for policy are identified throughout the chapter. All in all, we specify ten such lessons. In addition, we identify four opportunity areas for joint Nordic policy efforts.

The first and most general observation when comparing the energy innovation systems in the Nordic countries is that the innovation systems are significantly different from country to country. The Nordic countries all have extensive engagements in new energy technologies, however, the innovation systems vary considerably among other things with respect to institutional structures of the energy sectors, dominating technology regimes, natural resources and environmental challenges. The innovation systems and their dynamics are shaped by the specific conditions in the individual countries and by the specific activities historically. Moreover, the innovation systems with respect to each of the individual new energy technologies are also quite diverse and the maturity concerning application and industrial networks vary considerably. The differences among other things show in the actor set-ups, the industrial profiles, and the connections between market aspects and non-market aspects.

The first policy conclusion is that policy efforts should be aware of the variations of the innovation systems and capable of taking the differences into consideration.

More specifically, it is needed to have and maintain a 'strategic intelligence' (i.e. knowledge and insight) on the specific innovation systems and the individual technology areas at the ministries and other authorities that help governmental development of the energy policy. Technical expertise is needed at the authorities in addition to the other types of expertise e.g. expertise on legislation, economics etc.

The diversity in the innovation systems implies diversity in policy efforts. It would be difficult to establish one common policy of energy innovation within a country or across the Nordic countries. The policy efforts must be sensitive to the differences in the technologies. Comparative tables for each of the individual technology areas are given below.

A second general main point of the analysis is that it is characteristic for the energy innovation systems in the Nordic countries that there are many different types of actors involved in the systems. It is not only, say, industry companies or research institutions that define the systems. For example we have seen a number of fields where there is participation by branch organisations, environmental NGOs, public authorities (regional as well as national) and often also engaged entrepreneurs and citizens groups. This is apparent from the country studies as well as from the analysis of the participation in the public R&D programmes.

A narrow understanding of innovation systems with only industry companies and research institutions represented, or accounting only public funding institutions, does therefore not give an adequate understanding of the systems and the innovation dynamics. The multiplicity of actor groups is a central feature of the Nordic energy innovation systems. In this respect the energy innovation systems differ from many other industrial areas and from energy innovation systems in many other countries. The multiplicity of actor groups is a stronghold for Nordic energy innovation.

The second policy lesson is to pursue a policy that involves and is in dialogue with all relevant groups.

Having made these two basic points, we will proceed to discuss interaction dynamics. Comparison of the interaction dynamics in the innovation systems can be made through two parts of our material: the patterns of need integration dynamics observed in the country studies and the cooperation patterns in the public energy research and development programmes. Subsequently, we elaborate on a range of other features of the Nordic innovation systems and draw some further policy lessons.

Comparative table – Bioenergy

Bioenergy	Denmark	Finland	Norway	Sweden
Actors:				
- **Primary, leading actors**	• Government, policy • Energy companies (CHP, district heating)	• Energy industry • Pulp and paper industry, wood industry • CHP industry	• Traditional energy companies	• Paper and pulp industry • District heating, CHP industry • Policy
- **Supply industry (components, equipment, know how)**	• Suppliers of power plants and components • Consultancy, combustion, gasification know-how	• Considerable component manufacturing; boilers and other equipment (CHP, district heating)	• Wood industry	• Wood industry • Manufacturers of small boilers
- **Related industrial base**	• Agriculture • Machine industry • Biotech, latest years	• Pulp & paper • Wood industry • CHP, machine industry	• Wood industry • Energy companies	• Forest industry • Pulp & paper
Maturity:				
- **Application**	Widespread	Widespread, mature	Limited	Widespread
- **Industrial networks**	Some, relatively mature	Mature – full supply chain	Limited?	Mature – developed supply chains
- **Early mover / follower**	Forerunner on some bioenergy from agriculture/waste	Forerunner - CHP and power production	Slow mover?	
Domestic market drive of innovation	• Policy-driven utilization of national bio and waste resources	• High importance • Market deeply integrated with p&p and wood industries • Security of supply	• Limited • Electricity based systems, little CHP	• Some • Policy-drive • Industry use: Dominated by pulp/paper and wood industries
Export drive	Some exports; for years disappointing	Some; boiler techn: world lead	No	
Policy support - R&D	Considerable, recently also biofuel	Considerable, prioritized	Low priority Enova: support for heat	
Policy support – general / other	• Tariff support as part of policy plans • 'Biomass agreements' with agriculture and energy actors	• Investment subsidies • Price subsidy el-production • Support for energy harvesting in woods and energy investment in agriculture	Not priority area	• Green certificate scheme • Investment grants for small heat systems (residential) • CO2 tax •
Cooperation patterns – main characteristics	• Close cooperation btw. energy sector and tech. suppliers, agriculture and research • Top-down more than bottom-up	• Integrated with pulp & paper and wood industries • Close cooperation btw. energy industry and tech suppliers • Strong knowledge base • Swedish-Finnish connections	• Connections with Finnish/Swedish bioenergy industry • Some interest in combined natural gas and biomass	• Strong academic knowledge base • Swedish-Finnish connections
Major gaps / weaknesses in innovation system	• Focus on application – limited focus on business development	-	• Weak, scattered. Few actors.	• Competition from gas grid, weakening supplier industry

7.1 Interaction patterns: Need integrations

The complex interactions between need and demand articulations and technology opportunities ('need integrations') constitute an important part of the interaction dynamics in the energy innovation systems. Table Z summarizes the patterns of need integration in the three overall categories of interaction: 1) Integration through application (learning-by-using); 2) Integration through broad discussion; and 3) Integration through regulation.

The analysis shows that need integration through application and learning-by-using is a type of knowledge creation that is important and widespread in the Nordic energy innovation systems. In all countries we see that this dynamic is significant in many of the technology areas addressed. This confirms the findings from innovation studies of other sectors and technology areas that show that the Nordic countries, compared to many other countries, have excellent and well-developed competences in use-driven innovation (e.g. in the IT sector, Kyng & Mathiassen 1997 and Ehn 1992). Fuel cells to some degree appear as an exception to the general picture with a lower degree of learning from actual application and use, until now. The relatively one-sided emphasis on science push and technology push we see in this area is unusual in Nordic energy innovation. The closely connected hydrogen area however shows a number of demonstration projects and application experiments.

The third policy lesson is to consciously employ learning-by-using / learning-by-doing in the innovation and energy policies in a strategic way. Do not only focus on learning through formalised and academic knowledge production, but make learning-by-using/learning-by-doing and formalised knowledge production support and enforce each other.

Table 4: Need integration dynamics in technology areas in the Nordic countries. ("+" indicates that the need integration dynamics is significant. "%" indicates that the integration dynamic is significant, however in clearly negative direction and limiting for the development of the technology. "0" means that the dynamics is not significant.)

	Learning by using	Broad discussion	Regulation
Norway			
Wind	0 (intn. sub-supply: +)	0	0
Solar cells	+ + intn. markets	0	0 (intn. markets: + +)
Bio energy	0	(+)	(+)
Hydrogen / fuel cells	+ + / 0	+ / +	+ / +
Small Hydro	+ +	+	(+)
Sweden			
Wind	+	% % %	+ (> 2005: + +)
Solar cells	(+) intn. markets	0	(+)
Bio energy	+ + +	%	+ +
Hydrogen / fuel cells	0	(+)	0
Denmark			
Wind	+ + +	+ + +	+ + +
Solar cells	(+) intn. markets	+ +	(+)
Bio energy	+ +	+	+ + +
Hydrogen / fuel cells	(+)	+ / 0	(+) / (+)
Finland			
Wind	0 (sub-supply: + +)	(+)	(+)
Solar cells	(+)	?	%
Bio energy	+ + +	+	+ +
Hydrogen / fuel cells	(+)	0?	(+)
Iceland			
Hydrogen / fuel cells	+	+ +	+

Comparative table – Wind energy

Wind	Denmark	Finland	Norway	Sweden
Actors:				
- **Primary, leading actors**	• Early pioneers: Local citizens groups, small machine industry • Government • Wind turbine manufacturers	• Component manufacturers • Some regions: energy companies, planners	• Main electricity companies, sometimes in alliance with Dutch companies	• Some major energy and pulp & paper companies (earlier in opposition) • Policy makers and public debaters
- **Supply industry (components, equipment, know how)**	• World leading wind turbine manufacturers • Extensive component manufacturing • Planners and consultancy actors	• Considerable component manufacturing	• Local engineering and construction industry, towers	• Component manufacturing, e.g. bearings, cables, towers • Energy system developers (major energy companies)
- **Related industrial base**	• Agriculture's organisational tradition • Machine industry – SMEs	• Machine industry	• Limited role in hydro-based el-system • Visions about offshore petro competences used in offshore wind	• Limited role in hydro/ nuclear energy-industrial complex • Machine industry
Maturity:				
- **Application**	Widespread	Very limited	Limited	Limited
- **Industrial networks**	Mature – Industrial cluster	Strong sub-supply role	Limited, scattered – offshore: formative	Limited, scattered – some sub-supply
- **Early mover/ follower**	Early mover	Limited move	Late comer, stop-go	Early mower, but failed, now late mover
Domestic market drive of innovation	• Strong in the 1990s • Declined dramatically in 2000s • Offshore experience • Local ownership / support	• Little developed • Except in some coastal regions	• Weak drive in domestic market • Expectations vary following certificate market plans • Considerable local opposition from tourist industry	• Recent years – considerable drive, public focus and support • Poor legitimacy for many years (threat to nuclear power)
Export drive	Strong export turbine industry ++ Global markets	Considerable component exports	Partly driven by Dutch certificate market earlier	Components
Policy support - R&D	Some; priority area	Low priority	Low priority Some innovation support (Enova, IN)	Some
Policy support – general / other	• Multitude of policy efforts, strong feed-in in 1990s • More limited in 2000s; fluctuating policy support	• Investment support • Part of the general sustainability effort	• Low level feed in oriented renewables support	• Green certificates • Tradable emission rights • Investment subsidies (from 1991) • Offshore subsidies
Cooperation patterns – main characteristics	Very broad and extensive	• International supply chains	• Scattered	• Authorities and energy companies • Public debate
Major gaps / weaknesses in innovation system	• No. Multiplicity of actors, strong cluster (weaker home market, loss of strategic focus)	• Gap btw. components know how and system integration • Little effect of market support	• Low effect of market supporting efforts	• Absence of wind turbine industry • Opposition from mainstream energy actors for years

Need integration through broad discussion in public or in more or less open trans-disciplinary forums shows to be an important innovation dynamics in a number of technology areas. Here however, we see a difference between countries ranging from Denmark with much emphasis on discussion activities in most technology areas, especially wind energy, to Sweden with relatively little discussion on many of the technologies and even strongly negative discussion on, in particular, wind technology but also to an extent bioenergy. This finding is in accordance with opinion surveys that for example on bioenergy show a smaller share of the population in favour of, and larger opposition to, bioenergy in Sweden than in Finland and Denmark. Still the opinion in Sweden is more positive than the EU average (Eurobarometer 2007, see Appendix).

For Norway, the broad discussions are most significant in hydrogen & fuel cells and in small hydro. For wind energy and for solar cells the broader discussions have not been clearly significant. Especially the latter is interesting to notice given the considerable development in this area the latest years. There are however indications that the low degree of discussion guiding innovation in these technology areas is more the exception than the rule. On a number of other areas like for example large hydro power, C02 reduction and gas & petroleum there has been considerable public discussion (Tjernshaugen 2007, Borup 2007). The results for Finland concerning the significance of broad discussion are uncertain due to the lack of material on this point.

Informal interaction and discussions in broader forums are often of importance for energy innovation. A survey in Denmark shows that 60% of the energy actors as part of their activities participate in debates and broader discussions e.g. in media debate, in public debate meetings and hearings, and in meetings in interest organisations (please note that it is not an 'or' between the different activities, i.e. many actors participate in not only one, but a number of these kinds of activities). These activity patterns constitute a strength position of the energy innovation systems.

Integration of needs and demands through regulation are important in many of the technology areas. This is not least the case in the areas where we have seen significant changes in the energy systems in connection with the technology developments. ***Indeed, policy and regulation can be considered the single most important driver for innovation in the energy area. This is a fourth main lesson.*** To set-up ambitious goals and requirements to technology development through policy and regulation is crucial for high-quality energy innovation.

In Finland, Sweden and Denmark we see regulatory efforts that have been important for innovation in bioenergy and for the development of the domestic market. In Sweden, the C02 tax and investment subsidies, and later the green certificate scheme have helped form markets. The means in Finland and Denmark differ from this. Finland has used investment subsidies, price subsidies for electricity production and support of energy harvesting as well as agricultural energy investments. The emphasis on self-supply both locally and at national level has been an important factor behind the efforts. In Denmark the central, national planning of bioenergy from agricultural surplus products, employing tariff support as well as other measures, has led to considerable competence development and changes in the energy systems. To the extent that waste is biomass, policy and regulation have in Sweden and Denmark also been highly important for the integration of the waste area and the energy systems. This has created significant competence development and innovation and a led to a leading position internationally.

For solar cells the regulation and policy shaping especially the German market have driven the innovation in the Nordic countries, not least Norway, while innovation drive from national regulation and domestic markets is small. On the contrary, entry barriers and lack of, or slow, regulatory support of grid access have limited the innovation.

The need integration through regulation of the wind energy area in Denmark has been highly influential for the successful innovation in the area and the establishment of the strong industrial wind energy cluster. A multitude of regulatory efforts were established, primarily in the 1990s, combining economical measures with other measures in a strategic manner that tries to both support application and ensure competition between solutions. The measures range from e.g. planning and grid legislation, over tariff feed-in and green taxes, to certification systems and support of research and development. Also policy and regulation abroad are (and have been so since the 1980s) of significant importance for the wind energy innovation in Denmark.

Comparative table – Solar cells

Solar cells	Denmark	Finland	Norway	Sweden
Actors:				
- **Primary, leading actors**	• Small network of energy companies, NGOs, planners, researchers/ consultants • NGOs • General public, policy makers	• Holiday cabin owners • A couple of manufacturers of systems	• Manufacturers of silicon, wafers • New entrepreneurial companies with ties to el-metallurgical industry	• Public market formation programme • Module suppliers • Research and research –based companies
- **Supply industry (components, equipment, know how)**	• Power electronics • A few suppliers and retailers of modules • Wafer material (limited)	• Supply of modules • Off grid systems, signals	• Silicon, wafers, modules • Process know-how and equipment	• Module suppliers • Consultancy, engineering (system supply)
- **Related industrial base**	• Energy service for housing/buildings	-	• Strong el-metallurgical industry	
Maturity:				
- **Application**	Very limited	Limited (cabins)	Limited - niche (cabins, boats)	Limited
- **Industrial networks**	Scattered – niches	Scattered	Considerable supply industry network	Some (through support programmes)
- **Early mover / follower**	-	-	Relatively early mover in silicon wafers	Late mover
Domestic market drive of innovation	• Little	• Little developed	• Of little importance	• Off grid (cabins etc.) • Some on grid – through market formation programme • Entry barriers, grid access expensive
Export drive	Drive from German market and policy (niches: power electronics; rising silicon prices implied close down in wafer prod.)	International developing projects	Strong export drive, Germany, Japan and US markets	Demand from German policy/markets - module supply, consultants
Policy support - R&D	Limited priority	Low priority		Limited
Policy support – general / other	• Limited, late • Net-metering system, grid access	Investment support?		Limited priority
Cooperation patterns – main characteristics	Limited network - dedicated energy companies, NGOs, planners, researchers/ consultants Support from public – symbol of renewable energy Architecture (recently)	• Owners and designers of holiday cottages	• The solar cell industry has fostered a considerable supply industry • Engagement with Norwegian R&D – considerable research-industry cooperation	• Learning from market formation programme (new down-stream firms, institutional barriers) • Some connections btw research and cell manufacturers (spin-off) • Weak links between down-stream and up-stream actors
Major gaps / weaknesses in innovation system	• Scattered, disconnected • Gaps btw. actors (application, industry, research) • Poor integration in building sector • Little connection betw green prices and innovation	• Scattered, disconnected • Detached general energy systems	• Strong supply side – weak domestic demand side	• Weak and disconnected • Limited integration in energy systems • Not integrated with building sector • Lack of investment capital

In the other Nordic countries, need integration through regulation has been of less influence in the wind energy area. However, the green certificates in combination with influence from tradable emission rights and subsidies for offshore wind have to some degree changed the situation in Sweden in the recent years. Though investments in wind turbines in Finland is subsidised with a higher percentage degree than other renewables, only few installations and relatively little learning from the domestic market have appeared.

Given the very broad and far-reaching visions about ‘the hydrogen society’, ‘hydrogen economy’ etc. it is striking that the area of hydrogen and fuel cells is only to a very limited extent supported by regulatory efforts. Ambitious demands that can drive innovation and lead it in a fruitful direction have not been established. Such are needed if radical changes to a hydrogen society shall appear. An improved regulation effort could help closing the gap between technology developers and application areas and final customers and thus enhance the learning-by-using in the field.

It is important to note that even though policy measures supporting price structures and market formations appear in a number of cases, it is only in a few of these (e.g. wind energy in Denmark, innovation in solar cells due to German feed-in policy and to some extent bioenergy, in Finland) we see clear innovative learning and build-up of competences as a result. In many cases, the strategic focus of the market measures is not strong enough or timed well enough to foster technology innovation. For example, the market supporting efforts for wind in Finland, including e.g. green taxes/tariff subsidies, investment subsidies and green labelling schemes have only had marginal influence on innovation. Similarly, the green taxes and tariff support established in Denmark for solar cells and bio energy have not been central drivers for innovation in the fields. Moreover, the late timing of the Swedish tradable green certificate scheme is likely to form markets but not to drive innovation in the capital goods industry.

A fifth main conclusion is that there is potential for improvement of the innovative impact of market-oriented policy efforts.

7.2 Interaction patterns: Cooperation in public R&D programmes

The analysis of the cooperation in the public energy R&D programmes confirms that a multitude of actors appear in the Nordic energy innovation systems (see Figure X; for a complete description, see Appendix A). Many different types of actors are involved in the projects of the programmes. The participants are not only traditional research actors. Often industrial and business companies and energy companies participate. Moreover, it is not unusual that public authorities and actors like interest organisations (e.g. branch organisations and popularly based NGOs) are partners in the projects.[28] In this respect the Nordic countries are different to many other countries.

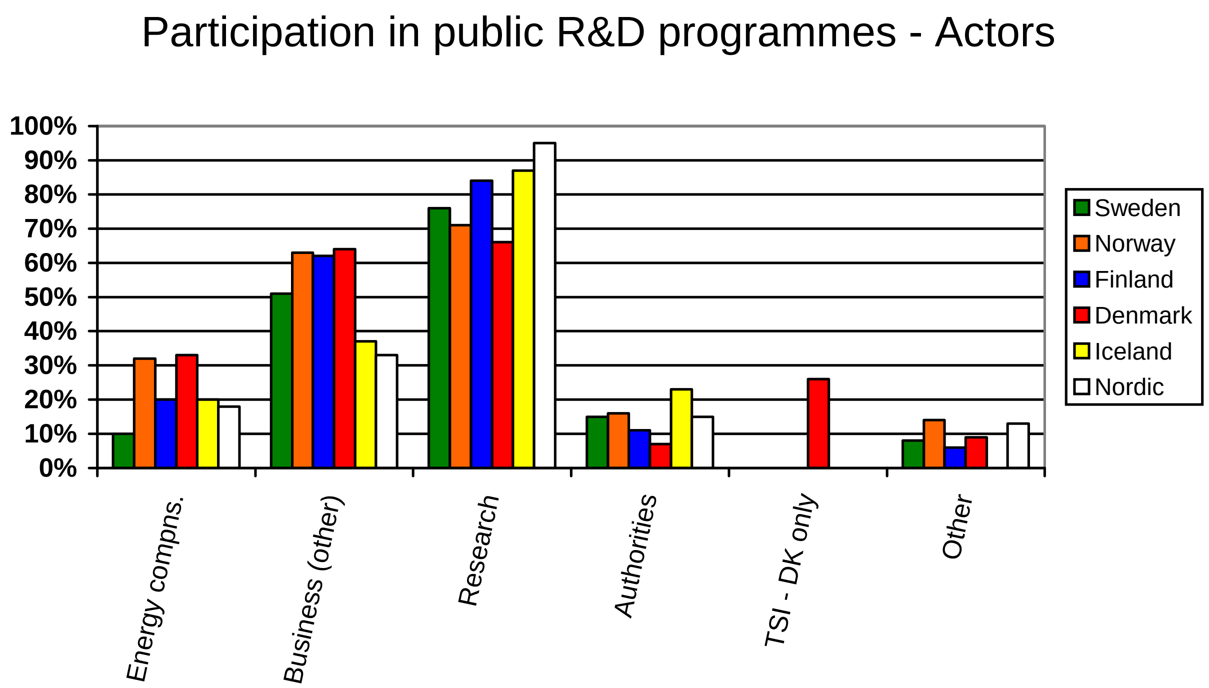
The analysis also shows that there are important differences between the participation patterns in the countries. The share of projects with research actors involved is relatively high in Finland, Iceland and Sweden, more than 3 out of 4 projects.[29] In Denmark 1/3 of the R&D projects are without research actors.

In Norway and Denmark there are more projects with companies[30] than with research actors. In nearly 2/3 of the projects there are business and industry actors involved, while energy companies are involved in half as many, 1/3 of the projects. For Sweden and Iceland, the share of projects with companies involved is considerably lower than in Denmark, Finland and Norway. Energy companies are represented in around 1/3 of the projects in Norway and Denmark, while it for the other countries is 20% or less; only 10% for Sweden. The share of project with business and industrial companies in Sweden, around 50%, is also lower than in Denmark, Finland and Norway, still higher than the 37% in Iceland.

[28] “Technological Service Institutions” (TSI) are only observed in Denmark.
[29] In the Nordic Energy Research programme the degree of research participation is 95%.
[30] “Companies” are the two categories Energy companies and Business companies taken together. The percentage figures cannot be added directly.

Comparative table – Hydrogen and fuel cells

Hydrogen / fuel cells	Denmark	Finland	Norway	Sweden	Iceland
Actors:					
- Primary, leading actors	• Regional authorities • Government • Research • Physics-chemistry based companies	• Industry • National R&D funding • Academia	• Oil & gas industry • Government • Environmental NGOs • Research	• Network between universities and industry (FC) • National research programmes (FC) • Hydrogen Sweden	• National energy authorities • Research
- Supply industry (components, equipment, know how)	• Fuel cells • Fuel reforming know how	• Some	• Industrial hydrogen production • Security handling	• Advanced material know-how (polymer components, steel, surfaces)	• Very limited • Learning related to using not manufacturing
- Related industrial base	• Physics-chemistry based industry • Wind power (surplus electricity)	• Established large industries • APU providers • Industrial gas • Defence industry?	• Petroleum industry and its equipment industry • Marine	• Vehicle industry • Tele communication • Military • New energy industry (wind/FC)	• No. • Hydropower and geother-mal power (surplus energy)
Maturity:					
- Application	Immature; demos	Demonstrations but close to early market	Immature – demonstration	No	Only demonstrations
- Industrial networks	Some – immature on many points	Some - strong international networks	Some – oil/gas industry	Immature	International networks
- Early mover / follower	Early mover	Early mover	Early mover		Early mover
Domestic market drive of innovation	• No • Experimental production • Demonstration	• Demonstration programme	• No • Demonstration	• No. • Experimental production and entrepreneurial experiments • Fuel cells plate production • Niche applications considered	• Demonstration
Export drive	Little; special uses	Potentially high		Some – fuel cell plates	No.
Policy support - R&D	High	Some	High	Some	• Some
Policy support – general / other	• Limited • Tax reductn for H2 and el cars	• Primarily R&D and demonstration	• Some - primarily R&D support	• Limited?	• Significant political support
Cooperation patterns – main characteristics	• Research – industry cooperation • Regions - developers	• Industry led cooperation with academia funded by government	• Industry – research • Public debate, interest organisations	• Cooperation academia-industry • Nordic hydrogen network	• International cooperation
Major gaps / weaknesses in innovation system	• Limited learning from application • Limited discussion, with gaps		• Gap from fuel cell research to application	• Lack of funding, long term • Gap to application areas and final customers	• Lack of manufacturing industry and country's small market



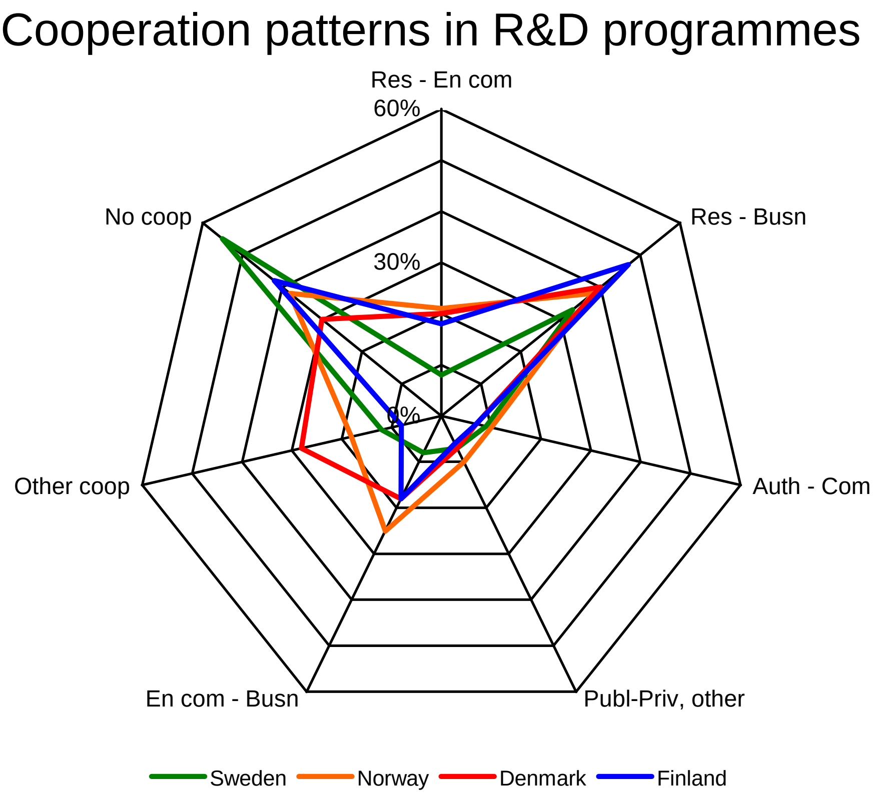
Authorities and similar public institutions appear in 1 out of 6 of the R&D projects in Norway and Sweden. In Finland and Denmark it is less often (11% respectively 7%). In Iceland, participation by authorities is most frequent with more than 20%. We accounted no projects with 'other' actors in Iceland.

There is a considerable amount of cooperation between different types of actors in connection to the public research and development programmes. The programmes constitute an important arena for cooperation in the energy innovation systems. There are however also on this point some major differences in the patterns of cooperation in the different countries. Figure X summarizes this. (For clarity reasons only the four largest countries are included here. See appendix for figure including Iceland and Nordic Energy Research.)

In general, Norway and Denmark show a broader cooperation picture than Finland and, especially, Sweden. There is cooperation between a larger variety of actors. For example Norway and Denmark have a relative large share of projects with cooperation between research and energy companies, between energy companies and business companies, and in the category 'other cooperation' accounting amongst other things cooperation between companies and branch organisations/NGOs (and in Denmark: cooperation with 'technological service institutions'). Iceland has also relatively much cooperation in connection to the R&D programmes. 43% of the projects have cooperation between research actors and companies. Finland is the country with largest share of cooperation between the research actors and business companies (47% of the projects).

Sweden stands out with significantly lower degree of cooperation in the public R&D programmes than the other countries. In more than half of the projects (55%) there is no cooperation across actor types. There is low degree of cooperation in most categories other than between research and business companies.

The pictures of the cooperation patterns in Sweden are moreover much more homogenous across the different technology areas than we see in the other countries where there is considerable variation between the technologies.



How to read these figures:
The figures show share of projects in the energy R&D programmes with cooperation across different types of actors. The types of actors are: Energy companies (En Com) and Other companies (business, industrial, service, etc.) (Busn). Together they make up the category Companies (Com). Moreover: Research institutions (Res), Public authorities (Auth) and 'Other actors' including e.g. interest organisations and NGOs. Authorities and research are accounted as public organisations while companies and interest organisations are accounted as private organisations.

'Res – En Com' thus shows share of projects with cooperation between research institutions and energy companies, while 'Publ-Priv, other' shows share of projects with other kinds of cooperation between public and private organisations than already mentioned, i.e. than 'Res - En Com', 'Res – Busn' and 'Auth – Com'. This could for example be projects with cooperation between research institutions and interest organisations. See details in Appendix A.

Apart from in Norway, solar cells appear as a relatively scattered area with less degree of cooperation than in average for the technologies and a divide between research and other actor types. Also hydrogen and fuel cells stands out as an area with relatively low number of projects with cooperation across actor types. (Again Norway is the exception with cooperation in more than 60% of the projects.) The picture from the R&D programmes on solar cells and hydrogen & fuel cells correspond well with the general picture from the country studies. It is obvious that ***programme managers as well as policy makers more generally should look for possibilities for improving the cooperation between the actors in these two areas. This is a sixth policy lesson.***

On a number of points, the patterns of interaction and learning in the energy innovation systems reflect central characteristics of the national innovation systems in general of the countries:

- For Finland, the large degree of cooperation between research and industry companies in the public research programmes and, moreover, the strong international orientation in the Finnish industry, not least in the machine industry.

- The low innovation degree in Norway, but large degree of interaction between actors. A relatively low amount of scientific activity, but a strong natural resource base (Grønning et.al. 2008 and science system indicators in Appendix B: scientific papers, citations, and R&D funding).

- The 'Swedish paradox': an innovation output that compared with the generally high 'input factors', large companies, large institutions and a strong scientific position (see the science system indicators in Appendix B), is low (Bitard et al. 2008). Part of the explanation may presumably be the relatively low degree of interaction between science/technology developers and users/practitioners. A complementary explanation may be the weak market formation for new power technologies in the past decades (see chapter 3) which has discouraged firms from entering the respective industries and thereby not formed a demand for innovative new solutions.

- Denmark with very large degree of interaction and cooperation (but with lower 'input factors' than some other countries, e.g., Sweden).

It is the seventh policy lesson that policy makers should be aware of the embedment in the general national innovation systems and the advantages and limitations this may imply.

7.3 Further characteristics of the energy innovation systems and additional policy lessons

In addition to the interaction dynamics described above we will point to a number of further, important features of the energy innovation systems identified in the analysis and continue to draw policy lessons. The features are:

- Embedment in existing energy regimes / energy systems
- Industrial bases and resources
- Opportunities for Nordic policy initiatives

Embedment in existing energy regimes / energy systems

The degree of embedment in the existing energy regimes and existing energy systems varies considerably between the technology areas. The innovation systems with respect to bioenergy for heat and power are in general closely related to the traditional energy companies. A considerable amount of learning appears in the energy companies and in the interaction between them and their suppliers of equipment. This is the case even though the energy companies often are not the primarily leading actors driving the innovation in bioenergy. On solar cells, on the contrary, many of innovation activities occur at a distance to the traditional energy companies and without the energy companies in a leading role. In Denmark though, a couple of energy companies are active on solar cells. The innovation systems on hydrogen and fuel cells show a similar picture with most of the activities taking place without the traditional energy companies in a leading role. In Norway however, the traditional energy companies, not least oil & gas companies, play an important role.

The existing energy regimes (energy companies, mainstream production/consumption patterns, main interest organisations, etc.) often appear as a barrier to innovation in the new energy technologies. This is for example seen in Sweden on wind energy and solar cells, in Finland on other renewables than bioenergy, and in Denmark on bioenergi and (earlier) wind energy. The resistance by the existing energy regimes can be more or less active and explicit. Active and explicit resistance is for example seen in Sweden by the electricity and nuclear regime against wind power. In Denmark the resistance has also been active at least to some extent, however, there usually is also some degree of interest from the energy companies, network operators etc. in the new technologies, among other things because it is part of the 'public service obligation' they have.

The eighth policy lesson is that policy makers cannot expect that large energy companies lead the way in the development and diffusion of all types of new energy technologies. It must be expected that they will be most inclined to go for technologies that build on their existing competencies and assets, e.g., carbon sequestration and storage technology for fossil based energy companies. If policy makers aim to stimulate a departure from these trajectories, they will need to provide market spaces in which the new technologies can thrive and develop.

Industrial bases and resources

Another important finding in our analysis is that the energy innovation systems in many cases are closely connected to and anchored in existing industrial areas, other than the energy area. New technology developments do usually not happen exclusively in the energy area, but draws heavily on knowledge bases, competences and the traditions in these other areas. The areas are of significant influence to the structures and dynamics of the innovation systems.

In the cases where we have seen strong industrial clusters emerging: bioenergy in Finland, Sweden and Denmark, solar cells in Norway and wind energy in Denmark, the connections to existing industrial bases and competences are significant.

For example, we see a bioenergy area in Finland and Sweden that is deeply integrated with the pulp and paper industry and the wood industry. In contrast to this, the bioenergy area in Denmark is strongly connected to the agricultural cluster.[31] The solar cell cluster developing in Norway in recent years is building on the electrometallurgical industry. Despite a weak national support system, Norway has seen remarkable growth in the solar industry. Based on strong materials competencies from electrometallurgical industry, good entrepreneurship and natural resources, Norwegian companies succeeded in developing a strong solar supply industry, first in wafers and subsequently in solar panels, with delivery on the world market. Norwegian solar industry thus followed an export led growth pattern, leapfrogging a weakly stimulated domestic market. The successful development of the Danish wind energy cluster is closely connected to the agricultural area and its organisation traditions. Moreover it builds on the competences and networks in the machine-component industry with its many small and medium-sized companies. In Finland, the well-developed machine-component industry is also of unique importance to the energy innovation systems. This shows e.g. within bioenergy, combined heat & power in general, and in the establishment of the strong sub-supplier position within wind energy.

The export drive of innovation we see in the solar cell area, the wind energy area and the machine-component area is an important factor. Still, the export is highly dependent on the industrial bases and competences at home.

The ninth lesson for policy makers is to develop an awareness of the competence base of the countries and to identify opportunities for diversification into new areas based on the existing competence base.

Yet our study also indicates that the resource base can provide an obstacle to diversification. Let us give a few examples. Norway has an abundance of biomass resources but stands out in the Nordic countries with a limited and fairly recent engagement. The monolithic focus on hydrobased electricity has not provided incentives for heat based biomass-fuelled systems, except for direct burning of wood in traditional fireplaces and ovens in off-grid cottages.[32] Norway also stands out as having better wind resources than Denmark but a very modest wind industry. Arguably, Norway is too richly endowed with resources: When the hydropower

[31] Also in Norway, where the bioenergy area is smaller than in Finland and Sweden, there are close connections to the wood industry. In Sweden and Denmark, the bioenergy area is also integrated with the area of waste handling.

[32] More recently, however, this is changing, as central heating is winning new terrain also in Norway. Industry as well as several energy companies have shown interest in this development.

period subsided; the petroleum period took over. The innovation systems built up for petroleum industry took most of the policy focus. Norway, as a 100% hydropower nation, did not have strong motivation to reform. The wind power sector comes on the radar only with the decline of petroleum engagement, and with the need for alternative deployment of offshore industry. Then it is taken up as a potential large scale export industry, and with expansive visions for an offshore super grid, with North-European dimensions.

Sweden also stands out with good wind resources but a late and slow engagement. This could have to do with the fact that the Swedish electro-industrial complex was primarily engaged in nuclear. The huge nuclear expansion created over-supply in the electricity market and a negative attitude to further engagement in renewables from the side of industry. Swedish activities have consequently been more oriented at quantity at low prices than supporting technological variety. The needs of the strong Swedish paper and pulp industry have been central in defining this path. The Swedish tradable green certificate scheme, continuous on this path and favours most mature renewable technologies, which is biomass based CHP. The existing resource base may, therefore, induce a lock-in effect whereby diversification into new areas is obstructed.

The tenth and final lesson for policy makers is that the exploitation of the opportunities inherent in the current competence bases (lesson nine) takes place in a context where there are inherent risks of lock-in from the resource base.

Opportunities for Nordic policy initiatives

With the relatively separate energy innovation systems in the Nordic countries, it can be difficult within a limited resource frame to establish a common Nordic policy effort generally on innovation in energy technology. A strategy of supporting and building up of more delimited areas can be chosen. The experiences from the analysis project have pointed to a number such areas. We will conclude with a tentative list of four such fields from the technology areas in focus of our study.

- **Gasification of biomass.** The Nordic countries have built up a considerable stock of knowledge and practical experience on gasification technologies for biomass. Nordic actors have leading competence on a number of points both concerning gasification of materials based on wood and on material from agriculture and farming. Networks in the Nordic countries already exist to an extent. A Nordic effort for market application, knowledge development and network support can be of significant importance for the chances of establishing the field as an industrial cluster with strong competitive advantages. Timing is here essential as clusters are being built up abroad, in particular in Germany and Austria.

- **Nordic bioenergy cluster and export of bioenergy technology.** The relatively well-established innovation system on bioenergy with world leading positions in application and knowledge production and with considerable networks between Nordic countries, can through a supportive effort be developed towards an actual industrial cluster of international strength. This requires a stronger emphasis on business development, industrialisation and export of bioenergy technology than until now. The effort could more specifically consist in two legs: An effort for identification of export markets and exploration of export opportunities. And an effort for continued networking and information exchange about industrial competences, application experiences and potentials of new, advanced knowledge in connection with bioenergy. A continued qualified and broad discussion about the sustainability impacts of the different bioenergy technologies is a prerequisite for development of a strong industrial cluster.

- **Integration of solar cells in construction industry and buildings.** The application side and domestic markets of solar cells in the Nordic region are relatively weak. Yet, this is one of the most promising technologies in the longer term and the technology is currently being industrialised on a large scale in Germany. The low integration in the construction industry and building traditions is one of the main gaps in the Nordic innovation systems. A joint Nordic strategic effort for solar cell integration in the construction industry and in building components may, therefore, be justified. Focus would be on knowledge development, demonstration projects and larger market formation programs as well as experience exchange that can bypass the shortcomings of the project-based tradition (i.e. scattered) within construction. Through the effort, Nordic industry can benefit from a demanding home market and the Nordic countries can influence the development of standards and certification/labelling systems on international level.

- **Nordic markets, networks and competences in the wind energy area.** With the strong Danish wind turbine industry and the important sub-supplier networks in the Nordic countries, support of new emerging competence areas e.g. wind turbine components, system integration technology, offshore technology, project development and planning, could lead to important synergies and further strengthening of the Nordic innovation system. In particular, this applies to the promising and huge off-shore market which could be the base on which the Nordic innovation systems could expand.

8. Sum-up of conclusions

Here we will briefly sum-up the conclusions of the study: There are great potentials in employing the innovation system perspective to the energy area. By adding the perspective to the more well-established policy perspectives of supply security, efficiency, and sustainability, it can help make business development and entrepreneurial activities go hand in hand with needed developments in the energy systems. Considerable synergies for reaching the energy policy goals can be obtained.

The innovation perspective cannot replace the other perspectives in energy policy, but is an important addition.

Energy innovation is a large economy and activity area in the Nordic countries and the investigation of innovation indicators moreover shows that the Nordic region in many cases is clearly visible in the general world picture of energy innovation and energy technology development. The visibility both appears with respect to practical know-how, industrial expertise and formalised scientific knowledge production. Not least within bioenergy and wind energy, but also in other areas of energy technology, are the Nordic activities internationally significant and the competences among the leading.

To this comes a relatively high awareness and engagement in energy concerns in society; in the population, and in a large number of organisations. This creates favourable conditions for high-quality demand articulation that can drive innovation and a degree of efficiency in the complex integrations between actual needs and technological and scientific opportunities. With a relatively flat power structure, culturally speaking, and a strong tradition for co-operation and discussion across actor groups, the Nordic countries have an advantage compared to many other countries concerning efficient need integration.

The energy innovation systems in the Nordic countries are significantly different from country to country and vary considerably, e.g., with respect to institutional structures of the energy sectors, dominating technology regimes, natural resources and environmental challenges. Also with respect to each individual of the new energy technologies addressed in the study, are the innovation systems highly diverse. It is important that policy makers are aware of the variations of the innovation systems and capable of taking the differences into consideration in the policy efforts. It is needed to have technology insight and a 'strategic intelligence' on the technology-specific innovation systems at the authorities that support policy development.

The patterns of interaction and learning in the energy innovation systems reflect characteristics of the general national innovation systems of the countries. The innovation systems for the individual energy technologies are often deeply embedded in and dependent on existing industrial bases and competence areas in the countries. Policy makers should be aware of this and must identify opportunities for development of new areas building on the existing bases.

The export drive of innovation we see in the solar cell area, the wind energy area and the machine-component area is an important factor. Still, the export is highly dependent on the industrial bases and competences at home.

The addressed technology areas have varying degree of embedment in the existing energy regimes. In general, policy makers cannot expect large energy companies to lead the way in the development and diffusion of all types of new energy technologies, as they will be mostly inclined to continue existing regimes rather than develop new trajectories.

To set-up ambitious goals and requirements to technology development through policy and regulation is crucial for high-quality energy innovation. Policy and regulation can be considered the single most important driver for innovation in the energy area. There is potential for improvement of the innovative impact of policy efforts. For example, policy measures supporting price structures and market formations appear in a number of cases, but it is only in a few of these we see clear innovative learning and build-up of competences as a result. In many cases, the strategic focus of the market measures is not strong enough or timed well enough to foster technology innovation.

The multiplicity of actor groups engaged in the innovation systems is a stronghold for Nordic energy innovation and policy should pursue to establish efforts that involves and is in dialogue with all relevant groups. Moreover, there is a considerable amount of co-operation in the Nordic energy innovation systems, for example between private and public actors. The innovation systems on solar cells and hydrogen & fuel cells however show to be scattered and with significant gaps. Policy makers and programme managers should look for possibilities for improving the cooperation between the actors in these two areas.

Learning through application (learning-by-using / learning-by-doing) is a type of knowledge creation that is significant in Nordic energy innovation. It is important that policy makers use this fact in a strategic way and make learning through application and formalised, academic knowledge production support and enforce each other.

With relatively separate energy innovation systems in the Nordic countries, it is not feasible to establish one, common Nordic policy effort generally on innovation in energy technology. A strategy of supporting more delimited areas can be chosen. The analysis points tentatively to four such areas, but also other areas might be considered. The four areas are: further strengthening of Nordic competence networks on biomass gasification; Nordic bioenergy cluster effort with stronger emphasis on business development and exports than until now; incorporation of solar cell technology in the construction and building industry; and, finally, Nordic competence and industry networks on wind energy with focus on new, promising areas like offshore technology.

Further points about the strengths and weaknesses of the innovation systems with respect to individual technologies can be found in the country chapters and in the comparative overview tables in Chapter 7.

In addition to the figures actually identified in the study's investigation of innovation indicators, it is confirmed that the field of energy innovation indicators is under development and not a well-established field, neither in itself nor as element in the more general statistics on innovation, industry and trade or on the energy sector. Only limited bodies of comprehensive and comparable data exist.

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Appendix A

Quantitative analysis of patterns of cooperation in national energy research & development programmes

Method remarks

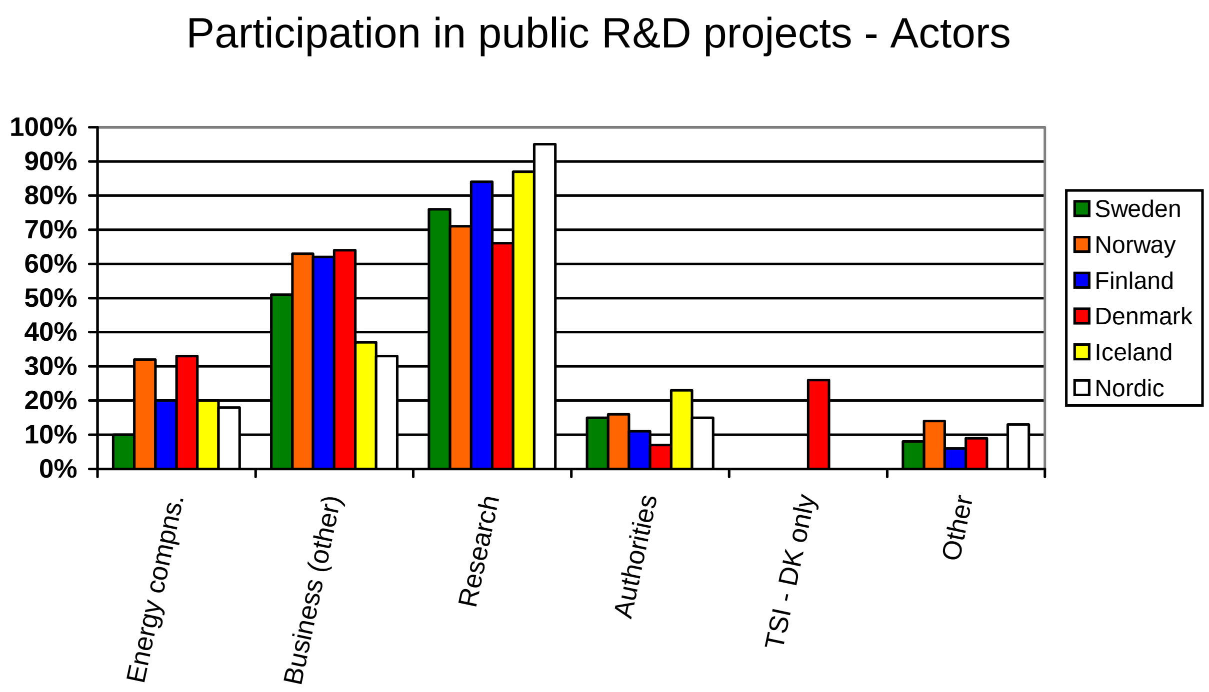
The analysis addresses the level of projects in the public, national R&D programmes. It is the purpose of the analysis of the projects in the public RD&D programmes to illuminate the degree of interaction between different actor groups. Therefore, the account covers cooperation across types of actors, not cooperation between actors of same type. That is, cooperation projects between for example two research institutions, or between two industrial companies, do not count, but cooperation between a research institution and an industrial company does.

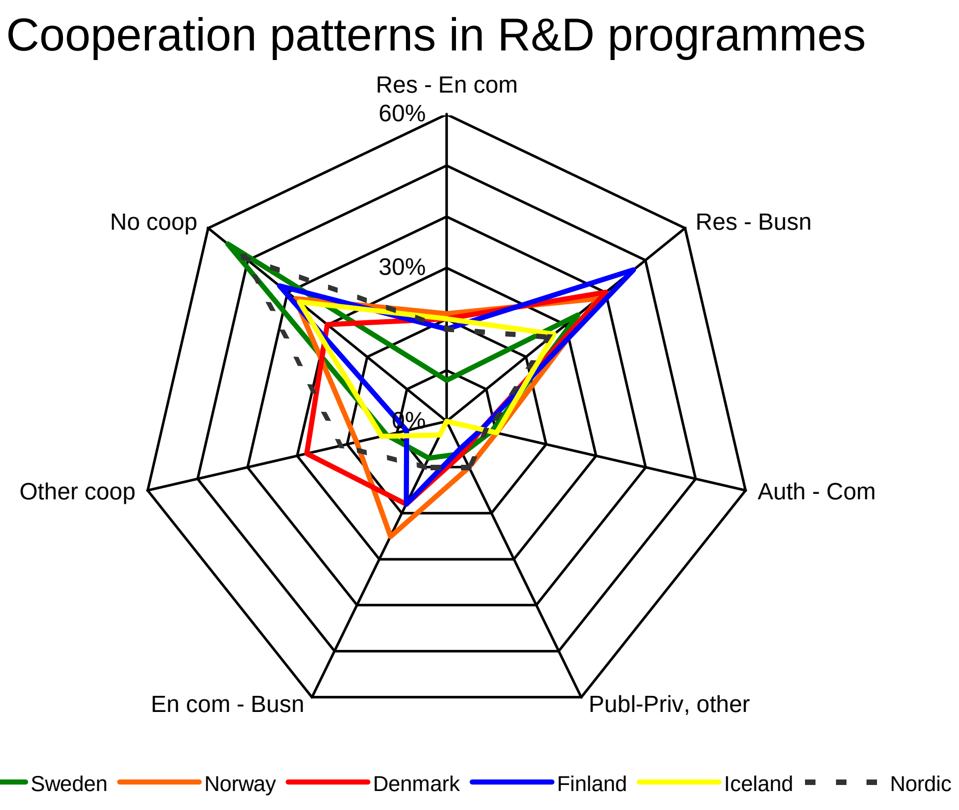
- "Other public-private cooperation" shows project with other types of public-private cooperation than between public research institutions and private companies. It can e.g. be projects with cooperation between authorities and interest organisations, between research and interest organisations, etc.
- "Other cooperation (across actor types)" can e.g. be between authorities and research institutions, between branch organisations and environmental NGOs, between companies and interest organisations, etc.
- As can be seen from the above, "no cooperation" means no cooperation across different types of actors, while cooperation between, e.g. two research institutions, or between two industrial companies, can take place in the projects in the "no cooperation" category.

Categories of actors
- Companies (Com)
    - Energy companies (En com)
    - Business (Busn)
      Other industrial and business companies; supplying technology, equipment, services, consultancy, etc.
- Research (Res)
- Public authorities (Auth)
- Other actors
    - Interest organisations
        - branch, industry associations, labour unions (Branch)
        - environmental NGOs, consumer organisations, citizens' groups (NGO)
    - Finance and investment institutions

The use of the categories of other actors has been very limited, though there are a number of projects with interest organisations involved. Most often they are branch organisations. Also NGOs appear now and then. In addition to these actor categories, Technological Service Institutes (TSI, technological service, testing, certification, standardisation, etc.) is used in the analysis of Denmark, where these institutions often appear. The TSIs are accounted as semi-public institutions. That is, they do not count in the figures for public-private cooperation, but appear in 'other' cooperation.

In order to be able to compare between technologies or between countries, percentage figures are made for all categories. In total, 1128 energy projects are covered.

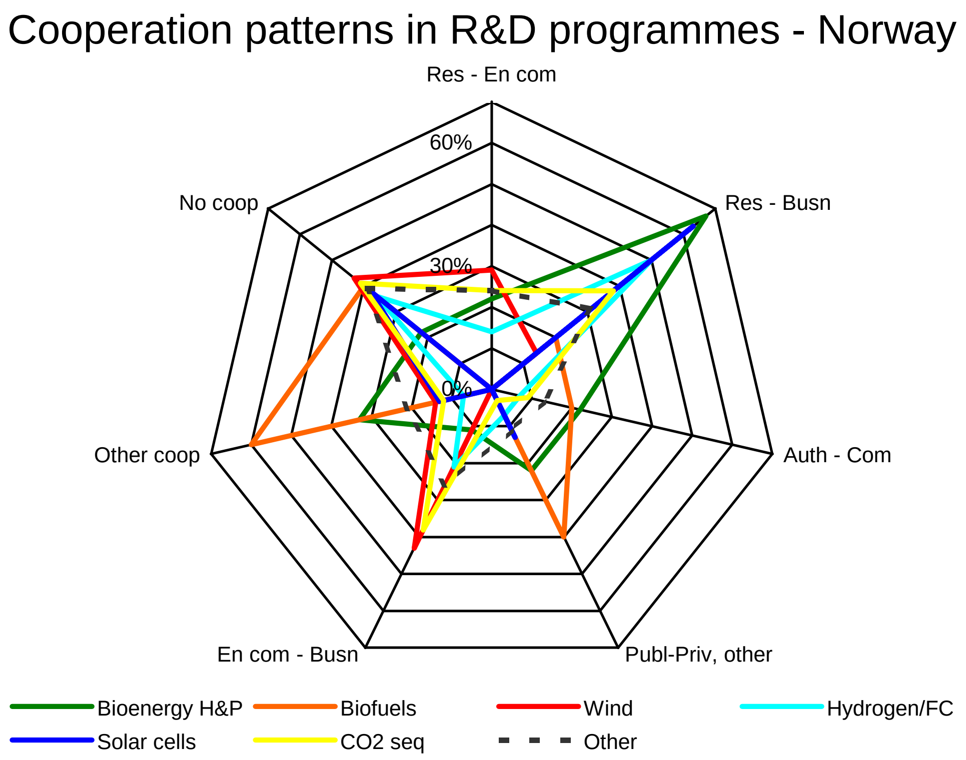

Participation in public R&D projects - Actors
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Energy compns.
Business (other)
Research
Authorities
TSI - DK only
Other
Sweden
Norway
Finland
Denmark
Iceland
Nordic


Cooperation patterns in R&D programmes
Res - En com
60%
30%
0%
Res - Busn
Auth - Com
Publ-Priv, other
En com - Busn
Other coop
No coop
Sweden
Norway
Denmark
Finland
Iceland
Nordic

Norway

Norway – Actors in national R&D programmes (Renergi and Climit; number of projects).

	Energy companies	Business companies (other)	Research	Authorities	Other	Total N
Bioenergy - H&P	2 (22%)	6 (67%)	9 (100%)	2 (22%)	2 (branch) (22%)	9
Biofuel – transport	0	5 (100%)	1 (20%)	1 (20%)	3 (2 branch, 1 ngo) (60%)	5
Wind energy	4 (57%)	4 (57%)	4 (57%)	0	1 (branch) (14%)	7
Hydrogen & fuel cells	7 (25%)	20 (71%)	22 (79%)	2 (7%)	2 (1 branch, 1 finans) (7%)	28
Solar cells	0	5 (63%)	8 (100%)	0	1 (branch) (13%)	8
CO2reduct.	14 (41%)	25 (74%)	22 (65%)	3 (9%)	2 (2 branch, 1 ngo, 1 finans) (6%)	34
Other	22 (35%)	31 (48%)	42 (68%)	16 (26%)	11 (branch) (18%)	62
Total	49 (32%)	96 (63%)	108 (71%)	24 (16%)	22 (14%)	153



Norway – Cooperation in national R&D programmes (Renergi and Climit; number of projects).

	Research-Companies (total)	Research-Energy com.	Research-Other com.	Authorities - Companies	Other publ-priv coop.	Energy com. – Other com.	Other cooper.	No cooper.	Total N
Bioenergy - H&P	7 (78%)	2 (22%)	6 (67%)	2 (22%)	2 (22%)	1 (11%)	3 (33%)	2 (22%)	9
Biofuel – transport	1 (20%)	0	1 (20%)	1 (20%)	2 (40%)	0	3 (60%)	2 (40%)	5
Wind energy	2 (29%)	2 (29%)	1 (14%)	0	0	3 (43%)	1 (14%)	3 (43%)	7
Hydrogen & fuel cells	15 (54%)	4 (14%)	14 (50%)	2 (7%)	2 (7%)	6 (21%)	1 (7%)	10 (36%)	28
Solar cells	5 (63%)	0	5 (63%)	0	1 (13%)	0	1 (13%)	3 (38%)	8
CO2reduct.	14 (41%)	8 (24%)	13 (38%)	3 (9%)	1 (3%)	13 (38%)	4 (12%)	14 (41%)	34
Other	24 (39%)	15 (24%)	19 (31%)	8 (13%)	7 (11%)	16 (26%)	13 (21%)	24 (39%)	62
Total	68 (44%)	32 (21%)	58 (38%)	16 (10%)	15 (10%)	39 (25%)	27 (18%)	58 (38%)	153

Programmes included are the RENERGI programme (Clean Energy for the Future; administered by the Research Council of Norway) and the Climit programme ('National programme for gas power technologies with CO_2 capture and storage'; administered jointly by the Research Council of Norway and Gassnova). Selected sub-programmes under ENOVA ('Innovative energy solutions', 'Introduktion of new technology' and 'Energy use – buildings and construction' (sub-programme 'Example projects') would also have been relevant to include, but it was not possible to obtain the information. The general oil & gas programmes (GASSMAKS, PETROMAKS, Demo 2000, Petrosam, Petropol) are not included. Activities under Innovation Norway was not considered relevant as they are not an research & development programme, but support of export, commercialisation and use of technology (energy sub-programmes are e.g. bioenergy, renewable energy, Wind & Sea, and Oil & Gas).

The projects covered are project started in 2005-2007 plus some from 2008. Moreover a limited number of projects started before 2005 and still running are included.

Data has been obtained from 82% of the relevant projects. The coverage of the different technology areas is good, 67-100% for the four focus areas of the study and with coverage of CO2 sequestration on 62% as the lowest. 'Other' projects include projects on e.g. energy efficiency technology, market development, energy systems, policy, hydro power and ocean power.

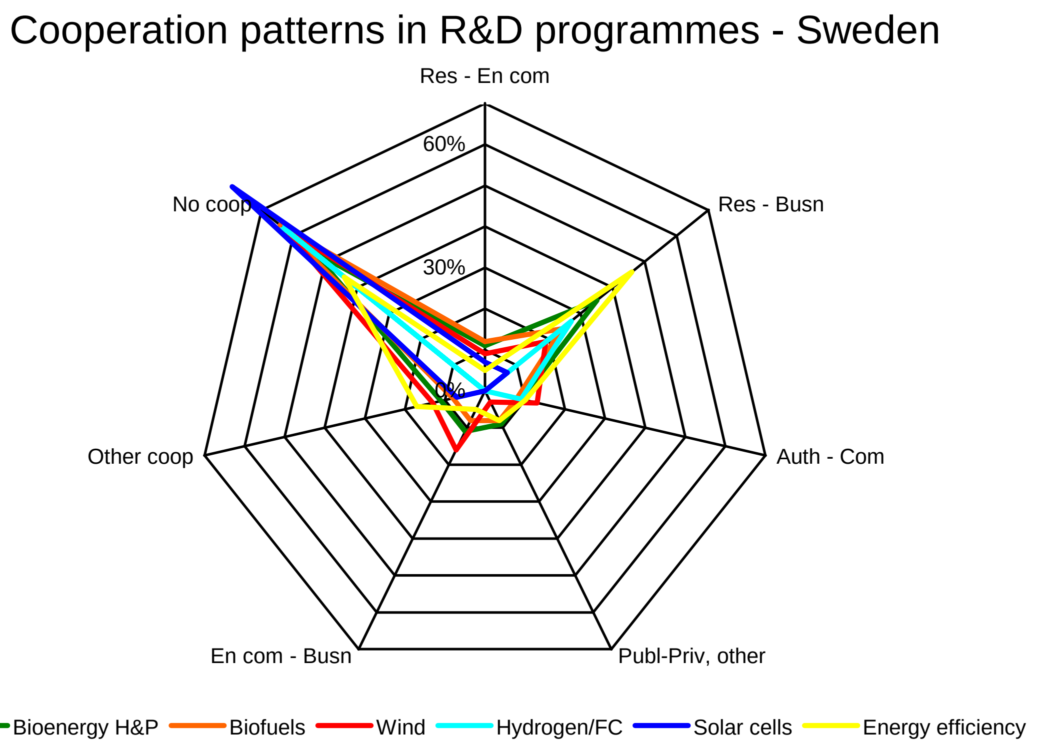
The large oil companies like Statoil, Norsk Hydro, etc. are counted as business companies (industrial companies, not in the category 'energy companies'). Energy companies are here counted as private companies, despite the fact that many are partly or fully publicly owned.

Sweden

Sweden – Actors in national R&D programmes (number of projects).

	Energy companies	Business companies (other)	Research	Authorities	Other	Total N
Bioenergy - H&P	6 (13%)	19 (41%)	39 (85%)	8 (17%)	4 (branch) (9%)	46
Biofuel – transport	3 (12%)	13 (52%)	16 (64%)	3 (12%)	2 (2 branch, 1 ngo) (8%)	25
Wind energy	7 (22%)	11 (34%)	25 (78%)	6 (19%)	1 (ngo) (3%)	32
Hydrogen & fuel cells	0	8 (73%)	6 (55%)	1 (9%)	0	11
Solar cells	1 (7%)	3 (21%)	12 (86%)	1 (7%)	0	14
Energy efficiency	4 (5%)	54 (64%)	64 (75%)	13 (15%)	11 (10 branch, 1 ngo) (13%)	84
Total	21 (10%)	108 (51%)	162 (76%)	32 (15%)	18 (8%)	212

Energimyndigheten / Swedish Energy Agency. Projects started in 2005, 2006 and 2007.



Sweden – Cooperation in national R&D programmes (number of projects).

	Research-Companies (total)	Research-Energy com.	Research-Other com.	Authorities - Companies	Other publ-priv coop.	Energy com. – Other com.	Other cooper.	No cooper.	Total N
Bioenergy - H&P	17 (36%)	5 (11%)	16 (35%)	4 (9%)	4 (9%)	5 (11%)	5 (11%)	25 (54%)	46
Biofuel – transport	7 (28%)	3 (12%)	6 (24%)	2 (8%)	2 (8%)	2 (8%)	2 (8%)	16 (64%)	25
Wind energy	7 (22%)	3 (9%)	6 (19%)	4 (13%)	1 (3%)	5 (16%)	4 (13%)	20 (63%)	32
Hydrogen & fuel cells	3 (27%)	0	3 (27%)	1 (9%)	0	0	0	7 (64%)	11
Solar cells	2 (14%)	1 (7%)	1 (7%)	0	0	0	1 (7%)	11 (79%)	14
Energy efficiency	39 (46%)	4 (5%)	39 (46%)	8 (10%)	7 (8%)	4 (5%)	14 (17%)	37 (44%)	84
Total	75 (35%)	16 (8%)	71 (33%)	19 (9%)	14 (7%)	16 (8%)	26 (12%)	116 (55%)	212

Energimyndigheten / Swedish Energy Agency. Projects started in 2005, 2006 and 2007.

Projects included are from the project database of the Swedish Energy Agency (the Energy Research Programme; including related (sub-)programmes on wind, solar cells and biofuels). The projects covered are projects started in 2005-2007. A small number of projects started before 2005 and still running in 2007 are moreover included.

Data has been obtained from 71% of the relevant projects. The coverage of the different technology areas is relatively good - above 75% for the individual technology areas, apart from energy efficiency (61%) and solar cells (54%).

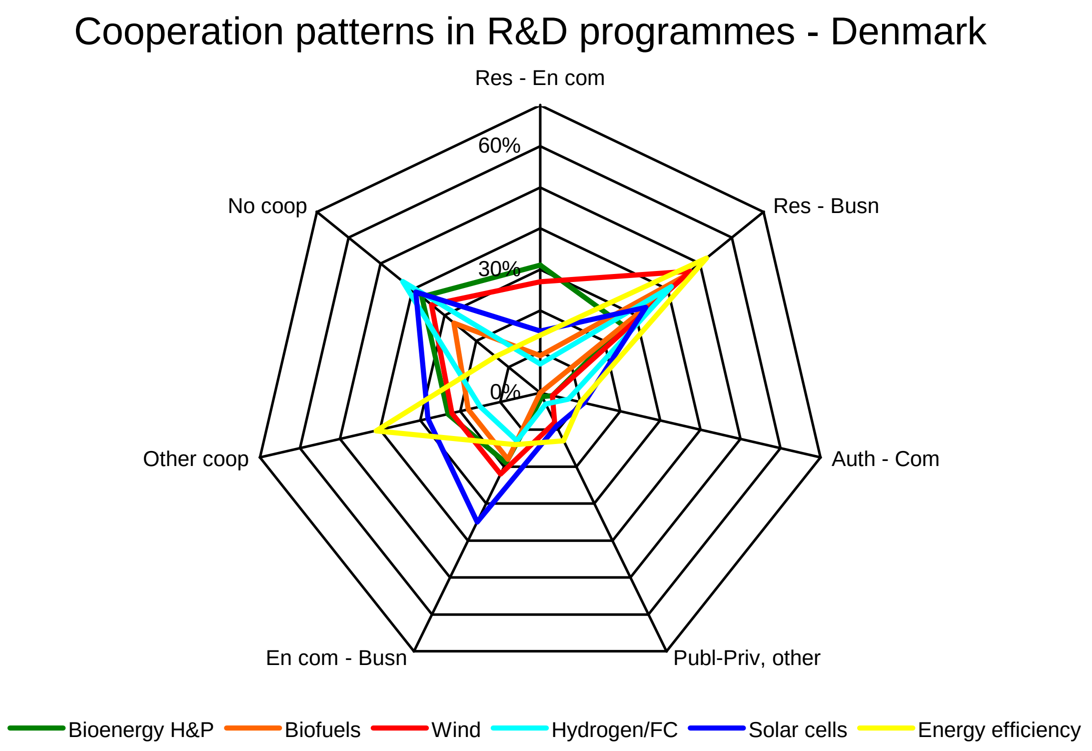
- There are relatively many projects in the Swedish R&D programmes that include international cooperation. No count has been made, but relatively to for example Danish R&D programmes the amount is clearly higher. Still the projects with international cooperation are a minority.
- The share of projects with research actors involved is higher than in Denmark. The share with companies is lower than in Denmark and Norway.

Denmark

Denmark – Actors in national R&D programmes (number of projects).

	Energy companies	Business companies (other)	Research	Authorities	TSI	Other	Total N
Bioenergy - H&P	66 (44%)	57 (38%)	103 (69%)	7 (5%)	41 (27%)	5 (branch) (3%)	150
Biofuel – transport	2 (18%)	7 (64%)	9 (82%)	0	1 (9%)	0	11
Wind energy	24 (38%)	38 (59%)	51 (80%)	3 (5%)	12 (19%)	6 (6 branch, 1 fin) (9%)	64
Hydrogen & fuel cells	11 (16%)	49 (72%)	43 (63%)	5 (7%)	9 (13%)	3 (1 branch, 2 ngo) (4%)	68
Solar cells	17 (37%)	39 (85%)	18 (39%)	5 (11%)	9 (20%)	6 (4 branch, 3 ngo) (13%)	46
Energy efficiency	42 (27%)	126 (82%)	102 (67%)	16 (10%)	57 (37%)	25 (18 branch, 7 ngo, 1 finance) (16%)	153
Total	162 (33%)	316 (64%)	326 (66%)	36 (7%)	129 (26%)	45 (9%)	492

Source: DENP database (Danish Energy R&D projects). Running projects 2007, plus new projects accessed medio 2008. The database covers all projects within the relevant programmes: PSO, EFP and ENMI. Own account building on the database and supplemented with project information and information material about organisations.



Denmark – Cooperation in national R&D programmes (number of projects).

	Research-Companies (total)	Research-Energy com.	Research-Other com.	Authorities - Companies	Other publ-priv coop.	Energy com. – Other com.	Other cooper.	No cooper.	Total N
Bioenergy - H&P	65 (43%)	46 (31%)	40 (26%)	5 (3%)	2 (1%)	29 (19%)	34 (23%)	56 (37%)	150
Biofuel – transport	5 (45%)	1 (9%)	5 (45%)	0	0	2 (18%)	2 (18%)	3 (27%)	11
Wind energy	36 (56%)	17 (27%)	30 (47%)	2 (3%)	5 (8%)	14 (22%)	14 (22%)	22 (34%)	64
Hydrogen & fuel cells	29 (43%)	5 (7%)	28 (41%)	5 (7%)	2 (3%)	9 (13%)	10 (15%)	29 (43%)	68
Solar cells	15 (33%)	7 (15%)	15 (33%)	5 (11%)	4 (9%)	16 (35%)	13 (28%)	18 (39%)	46
Energy efficiency	84 (56%)	22 (14%)	79 (52%)	16 (10%)	20 (13%)	21 (14%)	63 (41%)	22 (14%)	153
Total	234 (48%)	98 (20%)	197 (40%)	33 (7%)	33 (7%)	91 (18%)	136 (28%)	150 (30%)	492

Source: DENP database (Danish Energy R&D projects). Running projects 2007, plus new projects accessed medio 2008. The database covers all projects within the relevant programmes: PSO, EFP and ENMI. Own account building on the database supplemented with project information and information material about organisations.

The selected areas account for more than 90% of the projects in the research programmes. (The coverage within the selected area is 100%).

The technological service institutes (TSI) are considered neither public organisations nor private business companies. In the energy efficiency area, collaborations with these institutions account for a considerable share of the projects within ‘other collaboration’.

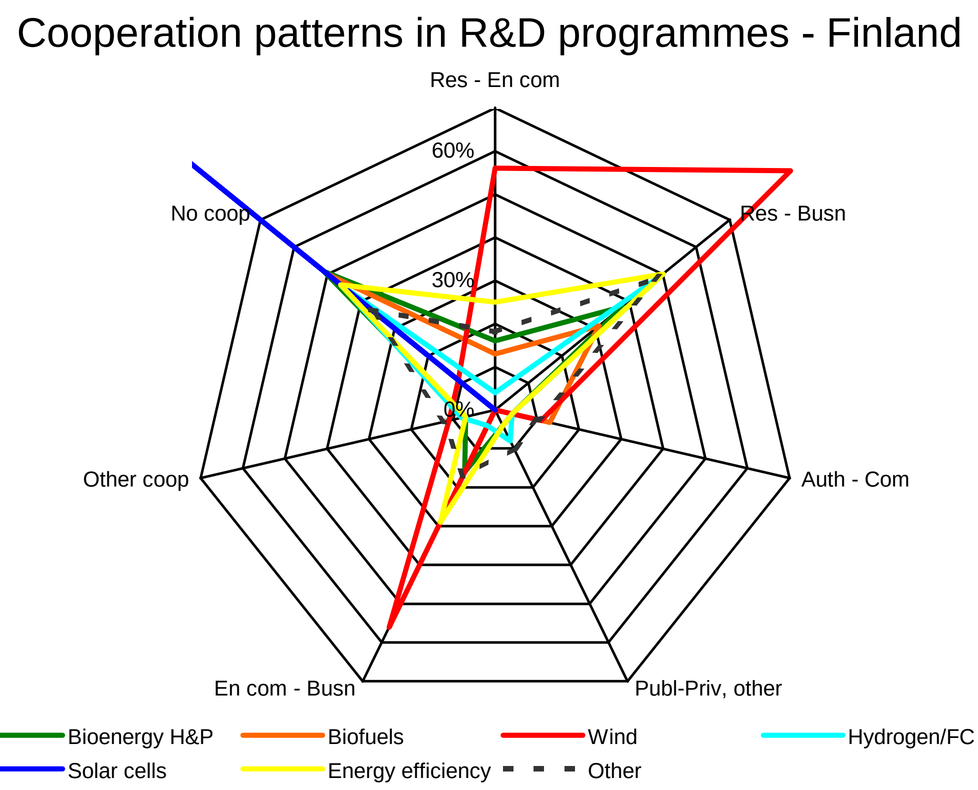
The recently established EUDP programme (Programme for Energy Technology Development and Demonstration) is expected to replace the EFP programme (the Energy Research Programme).

Parts of the statistical analysis of the Danish cooperation patterns in the public R&D programmes were carried out in the Danish project “Framework conditions, innovation and growth possibilities in the energy area”, carried out by DTU, Aalborg University and Danish Energy Industries Federation and funded by the Danish Energy Research Programme.

Finland

Finland – Actors in national R&D programmes (number of projects).

	Energy companies	Business companies (other)	Research	Authorities	Other	Total N
Bioenergy - H&P	9 (20%)	23 (51%)	41 (91%)	3 (7%)	2 (branch) (4%)	45
Biofuel – transport	4 (25%)	7 (44%)	14 (88%)	3 (19%)	0	16
Wind energy	5 (56%)	8 (89%)	9 (100%)	1 (11%)	0	9
Hydrogen & fuel cells	1 (4%)	20 (83%)	16 (67%)	2 (8%)	2 (1 branch, 1 ngo) (8%)	24
Solar cells	0	0	2 (100%)	0	0	2
Energy efficiency	8 (29%)	18 (64%)	24 (86%)	0	1 (branch) (4%)	28
Other	14 (18%)	49 (63%)	64 (82%)	14 (18%)	7 (branch) (9%)	78
Total	41 (20%)	125 (62%)	170 (84%)	23 (11%)	12 (6%)	202



Finland – Cooperation in national R&D programmes (number of projects).

	Research-Companies (total)	Research-Energy com.	Research-Other com.	**Authorities - Companies**	**Other publ-priv coop.**	**Energy com. – Other com.**	**Other cooper.**	**No cooper.**	**Total N**
Bioenergy - H&P	20 (44%)	7 (16%)	17 (38%)	2 (4%)	2 (4%)	7 (16%)	3 (7%)	23 (51%)	45
Biofuel – transport	5 (31%)	2 (13%)	5 (31%)	2 (13%)	0	2 (13%)	0	8 (50%)	16
Wind energy	8 (88%)	5 (56%)	8 (88%)	1 (11%)	0	5 (56%)	1 (11%)	1 (11%)	9
Hydrogen & fuel cells	12 (50%)	1 (4%)	12 (50%)	1 (4%)	2 (8%)	1 (4%)	2 (8%)	11 (46%)	24
Solar cells	0	0	0	0	0	0	0	2 (100%)	2
Energy efficiency	14 (50%)	7 (25%)	14 (50%)	1 (4%)	1 (4%)	8 (29%)	2 (7%)	13 (46%)	28
Other	39 (50%)	14 (18%)	38 (49%)	8 (10%)	8 (10%)	13 (17%)	9 (12%)	29 (37%)	78
Total	98 (49%)	36 (18%)	94 (47%)	15 (7%)	13 (6%)	36 (18%)	17 (8%)	85 (42%)	202

Programmes included in the analysis are:

- ClimBus Technology Programme 2004-2008, "ClimBus – Business Opportunities in Mitigating Climate Change", TEKES
- DENSY – Distributed Energy Systems 2003-2007, TEKES
- Fuel Cell Technology Programme 2007-2013, TEKES
- BioRefine, TEKES
- Fusion, TEKES
- Sustainable Energy (Hallbar Energi, Kestävä energia) 2008-2011, Academy of Finland, Suomen Akatemia
- SITRA Energy Program 2008-2012
- SITRA Environmental Programme 2004-2007, relevant parts (SITRA: Finnish Innovation Fund)

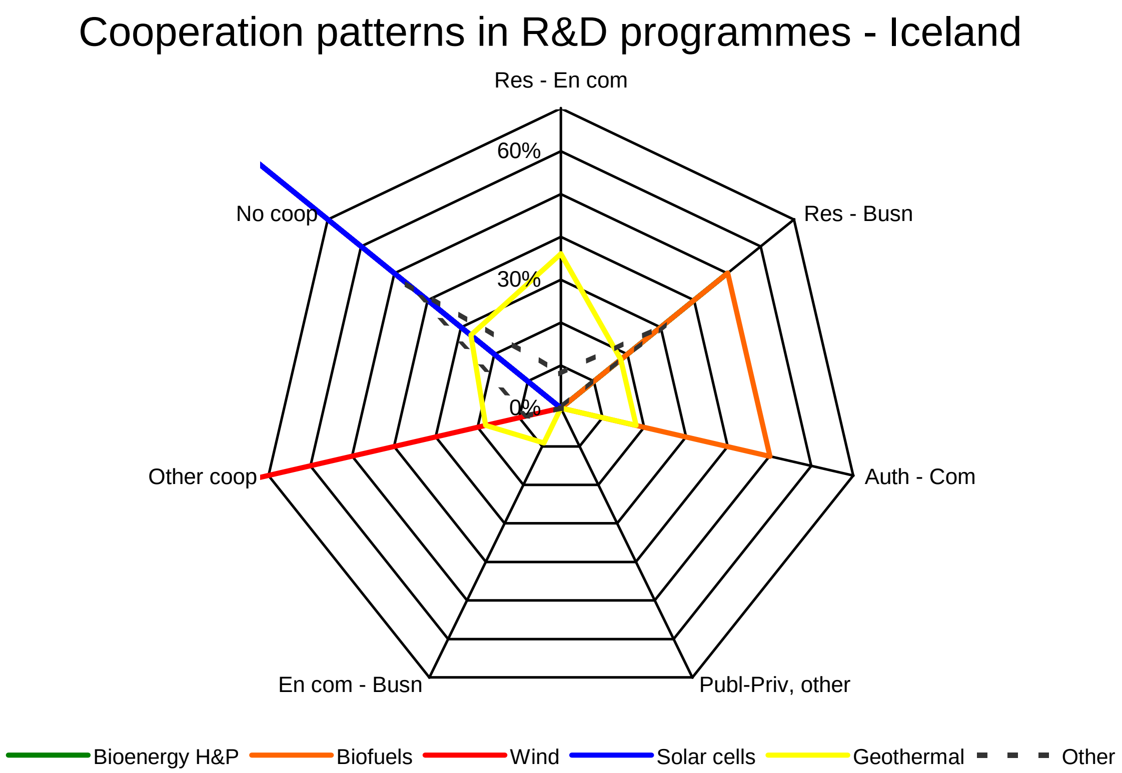
No information was available from the recently started programme Sustainable community technology programme, TEKES.

The coverage is relatively good with 62% of the projects covered. Bioenergy (for H&P) is covered with 75%. The lowest coverage is the category 'Other' where data is obtained on 54% of the projects. The subjects covered within the 'Other' category are many different areas, not least energy systems, socio-economy studies, power plant technology (combined heat & power, CO2 sequestration etc.).

Iceland

Iceland – Actors in national R&D programmes (number of projects).

	Energy companies	Business companies (other)	Research	Authorities	Other	Total N
Bioenergy - H&P	0	1 (50%)	2 (50%)	0	0	2
Biofuel – transport	0	2 (100%)	1 (50%)	1 (50%)	0	2
Wind energy	0	0	1 (100%)	1 (100%)	0	1
Solar cells	0	0	1 (100%)	0	0	1
Geothermal	5 (45%)	4 (36%)	9 (82%)	3 (27)	0	11
Other	1 (8%)	4 (36%)	12 (92%)	2 (18%)	0	13
Total	6 (20%)	11 (37%)	26 (87%)	7 (23%)	0	30



Iceland – Cooperation in national R&D programmes (number of projects).

	Research-Companies (total)	Research-Energy com.	Research-Other com.	**Authorities - Companies**	**Other publ-priv coop.**	**Energy com. – Other com.**	**Other cooper.**	**No cooper.**	**Total N**
Bioenergy - H&P	1 (50%)	0	1 (50%)	0	0	0	0	1 (50%)	2
Biofuel – transport	1 (50%)	0	1 (50%)	1 (50%)	0	0	0	0	2
Wind energy	0	0	0	0	0	0	1 (100%)	0	1
Solar cells	0	0	0	0	0	0	0	1 (100%)	1
Geothermal	6 (55%)	4 (36%)	2 (18%)	2 (18%)	0	1 (9%)	2 (18%)	3 (27%)	11
Other	5 (39%)	1 (8%)	4 (31%)	0	0	0	1 (8%)	6 (46%)	13
Total	13 (43%)	5 (20%)	8 (27%)	3 (10%)	0	1 (3%)	4 (13%)	11 (37%)	30

Programmes included in the analysis are:
- National Energy Fund, Orkustofnun (National Energy Authority)
- RANNIS (The Icelandic Centre for Research) – energy projects
- Environmental and Energy Research Fund (Orkuveita Reykjavíkur, Reykjavik Energy) – energy projects

Projects included are current and recently ended projects. The coverage is around 50% in general; 69% for geothermal technology, 100% for bioenergy, biofuels and solar cells (very few projects), 50% for wind, and at least 39% for the 'other' category. Unfortunately is has not been possible to obtain information on the four identified projects on hydrogen.

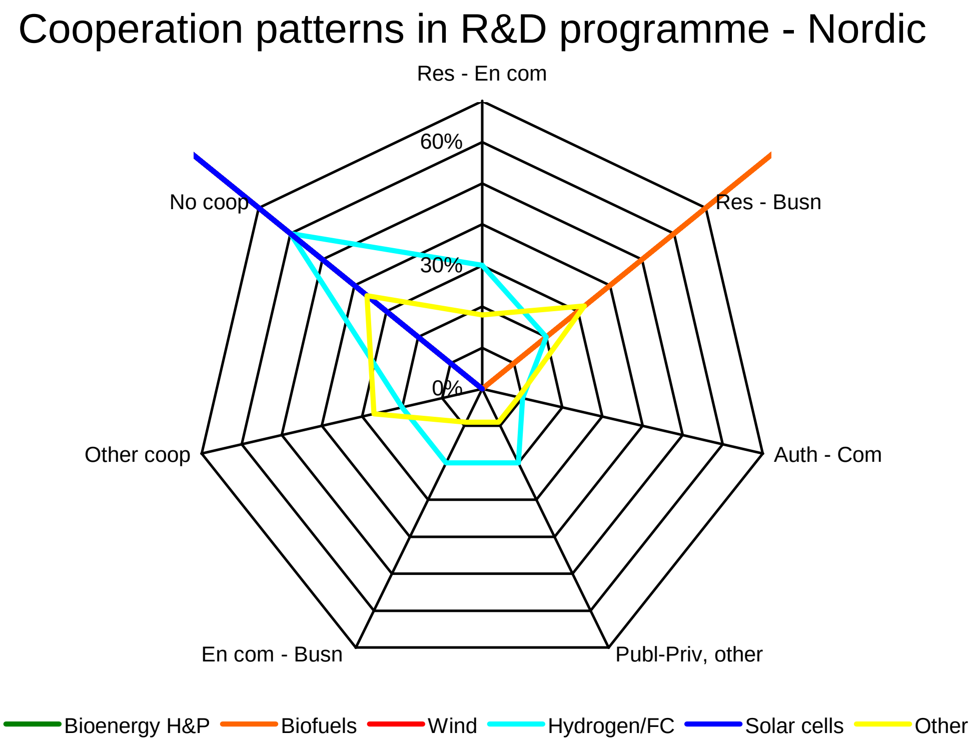
Common Nordic - Nordic Energy Research Programme

Nordic – Actors in the Nordic Energy Research programme (number of projects).

	Energy companies	Business companies (other)	Research	Authorities	Other	Total N
Bioenergy - H&P	0	0	2 (100%)	0	0	2
Biofuel – transport	0	1 (100%)	1 (100%)	0	0	1
Wind energy	0	0	2 (100%)	0	0	2
Hydrogen & fuel cells	3 (30%)	3 (30%)	9 (90%)	1 (10%)	2 (1 branch, 1 ngo) (20%)	10
Solar cells	0	0	2 (100%)	0	0	2
Other	4 (18%)	9 (41%)	21 (95%)	5 (23%)	3 (branch) (14%)	22
Total	7 (18%)	13 (33%)	37 (95%)	6 (15%)	5 (13%)	39

Source: Nordic Energy Research (2007): Annual report 2006, www.nordicenergy.net accessed primo 2008. Projects from the project periods 2003-2007 and 2007-2010 are covered.

All projects within the programme of Nordic Energy Research are covered. In almost all the projects, there is cooperation across national borders.



Nordic – Cooperation in Nordic Energy Research programme (number of projects).

	Research-Companies (total)	Research-Energy com.	Research-Other com.	Authorities - Companies	Other publ-priv coop.	Energy com. – Other com.	Other cooper.	No cooper.	Total N
Bioenergy - H&P	0	0	0	0	0	0	0	2 (100%)	2
Biofuel – transport	1 (100%)	0	1 (100%)	0	0	0	0	0	1
Wind energy	0	0	0	0	0	0	0	2 (100%)	2
Hydrogen & fuel cells	4 (40%)	3 (30%)	2 (20%)	1 (10%)	2 (20%)	2 (20%)	2 (20%)	6 (60%)	10
Solar cells	0	0	0	0	0	0	0	2 (100%)	2
Other	10 (45%)	4 (18%)	7 (32%)	2 (9%)	2 (9%)	2 (9%)	6 (27%)	8 (36%)	22
Total	15 (38%)	7 (18%)	10 (26%)	3 (8%)	4 (10%)	4 (10%)	8 (21%)	20 (51%)	39

Source: Nordic Energy Research (2007): Annual report 2006 and www.nordicenergy.net accessed primo 2008. Projects from the project periods 2003-2007 and 2007-2010 are covered.

Appendix B: Innovation indicators[33]

The aim of this appendix is to investigate a number of possible indicators for innovation in the energy sector. The area of energy innovation indicators is a field under development, and only limited bodies of comprehensive and comparable data exist. The goal is to make a few quantitative accounts of the indicators, though it was expected that the work on some points would be explorative rather than resulting in full comprehensive statistics.

The technology areas indicated in the project description were: 1) bio energy, 2) hydrogen / fuel cells 3) photovoltaics, and 4) wind energy. It has become clear that the area of bio energy actually contains two distinct areas: biomass for fuel (liquid or gaseous, but predominantly bio ethanol and bio diesel) and biomass for heat and power production. Also the area of hydrogen / fuel cells contains so many distinct areas that an aggregation of data makes no sense. Therefore, this study will focus on the following areas of technology:

- wind energy
- solar cells (photovoltaics)
- hydrogen
- fuel cells
- bio fuel
- biomass for heat and power

The indicators examined in this part of the study were:

- Export data is a related indicator that is covered in existing projects (at least to some extent) and will therefore not be traced further here. Data exists on EU-15 countries import and export of energy technology and equipment. The data is not broken down into types of energy technology.
- Venture capital attracted to the area of energy technology. Again accessibility of comparable data is a problem. But some available information is included in the project. The study showed that limited publicly available information is available.
- Traditional bibliometric indicators: number of publications, citations and patents within an area of energy technology are extracted from existing databases.
- Governmental R&D expenditures related to energy technologies are to a considerable degree known from IEA/OECE databases.
- Private sector (firms') expenditures on energy R&D. As Energy is not contained in traditional NACE-codes, accessibility of comparable data is usually a prohibitive factor for further analyses of this indicator. Furthermore, it was very difficult to obtain full sets of reliable and globally comparable data.
- Market formation indicator: Market sizes. For most energy producing technologies trade literature exists that lists cumulated installations in MW and the installations made in recent year. For some areas, alternatively, the amount of energy produced by the technology (in GWh, GJ or similar unit of energy, mass or volume) can be found. The analysis is based on publicly available information as the cost of market analyses from private consultancies are beyond the frames for this project.
- Industry formation indicator: Marked shares of Nordic companies within specific energy technology areas. Trade literature in many cases makes accounts of the market shares of different companies in the area. Sometimes also information on the country/countries of their main presence is available. A limitation here might be that it is primarily companies with larger market shares that are covered. Another problem is the increasing internationalization of industrial production making it difficult to determine the nationality of large firms.

On the subsequent pages, data on bibliometrics, governmental R&D, market formation indicators and industry formation indicators for each of the technologies are reported. Data for the Nordic region is compared with the total world picture (shown as composed by EU, USA, Japan and Rest Of the World (ROW)).

[33] Walter J. Sanchez is co-author on this section.

Firstly, however, a couple of further remarks concerning the indicators jobs and venture capital are given. Jobs and job creation is high on the political agenda in some countries. Consequently, several energy technology actions plans and roadmaps have considered employment effects of increased use of the technology in quest. From a macro economical point of view job creation is not in itself an aim for governmental science and innovation policy. Macro economists put more focus on improvements of the productivity of a sector or a nation. Following this, cutting jobs while maintaining or even increasing market shares and thereby increasing productivity is the desired goal. The challenge for highly industrialised countries is not just to create jobs but to create well-paid jobs.

A recent Nordic survey indicates large differences between four Nordic countries (Trong, 2007). See figure 3. These differences are likely to be due to general differences in industrial structure in the four countries. In Denmark revenues in the energy sector have increased more than the revenues in industry in general, there are greater increases in revenues per full-time employee in the energy sector than in industry in general. This is not the case in the other Nordic countries.

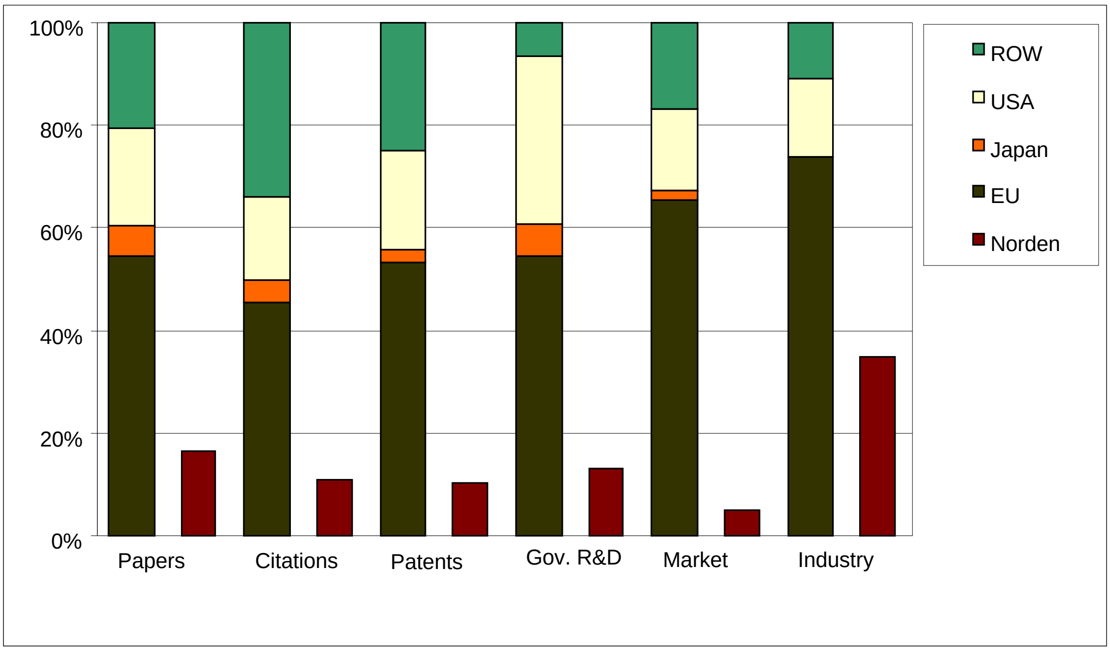
	Annual revenue per full-time employee in the energy technology industry €	Annual revenue per full-time employee in industry in general €
Denmark (2004)	285 000	207 000
Finland (2005)	245 000	270 000
Norway (2005)	241 000	300 000
Sweden (2005)	213 000	230 000

Figure 2. Annual revenue per full time employee in energy technology industries in four Nordic countries. Source: Trong (2007).

Venture capital attracted to an area of technology is also an interesting indicator, but again accessibility of comparable data for the Nordic countries is a barrier for more detailed analyses in this context. A recent report from the consultancy New Energy Finance has analysed issues such as venture capital, private equity, incubators and investments funds in the area of sustainable energy[34]. The IPO value in the energy technology area boomed in 2006 with an increased on 156% measured on global level[35]. Solar energy and bio fuels are the primary driving areas in this (Lux Research, 2007). There is not yet publicly available information on Nordic level on venture capital and private equity attracted to firms related to energy technologies. In Denmark, the venture capital investments in renewable energy and other eco-innovation areas has developed from being almost invisible in the general picture of the venture area in the late 1990s to accounting for 7% of the investments in 2006 (Vækstfonden, 2007). Venture capital and IPO value might also count as indicator for firms' or sectors competitiveness or at least as the markets expectation for future competitiveness. In other Nordic countries erratic evidence (i.e. news paper stories, press releases, etc.) suggest that venture capital is playing an increasingly important role in relation to CleanTech.

[34] http://www.unep.org/pdf/SEFI_report-GlobalTrendsInSustainableEnergyInverstment07.pdf
[35] Initial Public Offering (IPO) is the first sale of stock by a private company to the public.

B.1 Wind Energy



	Papers	Citations	Patents	Gov. R&D	Market	Industry
Period	*1996-2006*	*1996-2006*	*1996-2006*	*1996-2005*	*Acc. 2006*	*2006*
Unit	*number*	*number*	*number*	*Million €*	*GW*	*MW*
EU	583	833	1087	530	48.6	11415
Japan	63	76	51	60	1.5	0
USA	203	296	393	317	11.6	2326
ROW	219	622	510	65	12.6	1696
Total	1068	1827	2041	972	74.3	15439
Of which						
Denmark	117	120	144	82.8	3.1	5342
Finland	5	14	19	8.1*	0.1	0
Iceland	0	0	2	-	-	0
Norway	10	16	8	8.3	0.3	0
Sweden	43	48	38	28.3	0.6	0
Norden	175	198	211	128	4.0	5342

Definitions and sources:

- **Papers and Citations**: Include those listed in the Science Citation Index. The search string used for the search is: 'wind power(5w)plant? or wind(5w) turbine?'.
- **Patents:** Includes patents listed in Derwent World Patents Index. The search string used for the search is: 'wind power(5w)plant? or wind(5w) turbine?'.
- **Governmental R&D expenditure**: is defined by IEA as government energy technology R&D budgets in million Euro (2005 prices and exchange rates). ROW here only includes IEA member countries.*) Finland: only 1996-2003. Source: IEA Energy Statistics.
- **Market indicator**: is defined as the accumulated installed capacity of wind turbines measured in GW by the end of 2006. Source: International Wind Energy Development – World Market Update 2006 – Forecast 2007-2011, BTM Consult ApS – March 2007.
- **Industry indicator**: is defined as MW supplied in 2006 by the 10 leading manufacturers of wind turbines. 689 MW or 4% was produced by other firms than these ten. Home country of each manufacturer is used for the indicator disregarding that each manufacturer might manufacturer in plants in different places all over the world. This indicator does not take into account supplying industries. Source: International Wind Energy Development – World Market Update 2006 – Forecast 2007-2011, BTM Consult ApS – March 2007, (Page 23).

B.1.1 Introduction

Sources and databases related to wind power, wind turbines and manufacturing are very accessible. It is one of the best documented energy technologies at the moment. There are several associations and regional networks that gather information about the market size of wind energy and its development. For instance, in Europe (European Wind Energy Association, EWEA), in USA (American Wind Energy Association, AWEA) and at the global level (World Wind Energy Association, WWEA and the Global Wind Energy Council, GWEC) are referential organisations or institutions that present annual reports concerning figures related to e.g. installed capacities, manufacturing and market share. The case of wind energy in relation to the successful management of gathering data and their accessibility can be referential for other energy technologies.

B.1.2 Publications, citations and patents

Bibliometric searches are carried out for publications and citations in Science Citation Index (Web of Science) and Derwent World Patents Index (patents). Both of which are hosted online via STN International.

In all three cases the search counts authors of the selected articles distributed over the selected countries or groups of countries (e.g. EU). A single publication with co-authors from both Germany, USA and Japan will count for all three countries.

Values comprise cumulated figures for the time span of 1996-2006.

The search strings used for this report are the following:

- Science citation index: wind power(5w)plant? or wind(5w) turbine?
- Derwent world patents index: wind power(5w)plant? or wind(5w) turbine?

The key quality issue concerns the selection of search strings and exclusion of articles, citations, and patents irrelevant for the specific task. Concerning the latter issue no efforts have been taken to exclude "false" data except adjusting search words.

B.1.3 Governmental R&D expenditures

This indicator includes Government energy technology R&D budgets. For wind the data includes data for concerning the following issues: converter development; system integration; on-shore applications; off-shore applications; other.
The data is downloaded from IEAs' "Access Database (2006 Edition)". See:
http://www.iea.org/Textbase/stats/rd.asp
Data is available since the 1970s. Limitations are affiliated with data for two or three years are not available from a few countries; among others Belgium, Finland, France, and the Netherlands. The indicators here are cumulated figures for the years 1996 to 2005.

Figures are listed in Million Euro (2005 prices and exchange rates).

In general the quality of data on wind is among the more reliable.

A general assessment of the quality of the data can be found in:

- Energy R&D Statistics in the European Research Area. Final Report (2005) Directorate-General for Research, Sustainable Energy Systems, EUR 21453. ISBN 92-894-8964-2

B.1.4 Market indicator

The market indicator is defined as accumulated installed capacity (measured in GW) of wind turbines by the end of 2006.

Primary source:

- International Wind Energy Development – World Market Update 2006 – Forecast 2007-2011, BTM Consult ApS – March 2007. I. C. Christensens Allé 1, Ringkøbing, DK. Madsen, www.btm.dk

The parameters of the source of installed capacity are based on figures gathered in different market analyses of wind turbines. The market assessment and business development of wind turbines are based on the outputs presented by feasibility studies, wind resource assessments, wind farm management and project appraisals. These types of studies require diligence during the investigations, financial analysis, technical evaluations of wind turbines, performance, and reliability assessments of existing and planned wind energy projects.

The data covers figures globally, and they are updated by the end of 2006 by BTM Consult Aps.

B.1.5 Industry indicator

This indicator is defined as the percentage of annual sold capacity during 2006 by the leading manufacturers of wind turbines. Furthermore, the home country of each manufacturer is used for the indicator disregarding that each manufacturer might manufacturer in plants in different places all over the world. The Top 10 wind turbine manufacturers in the world maintained their overall position by supplying 95.2% of the 2006 installations.

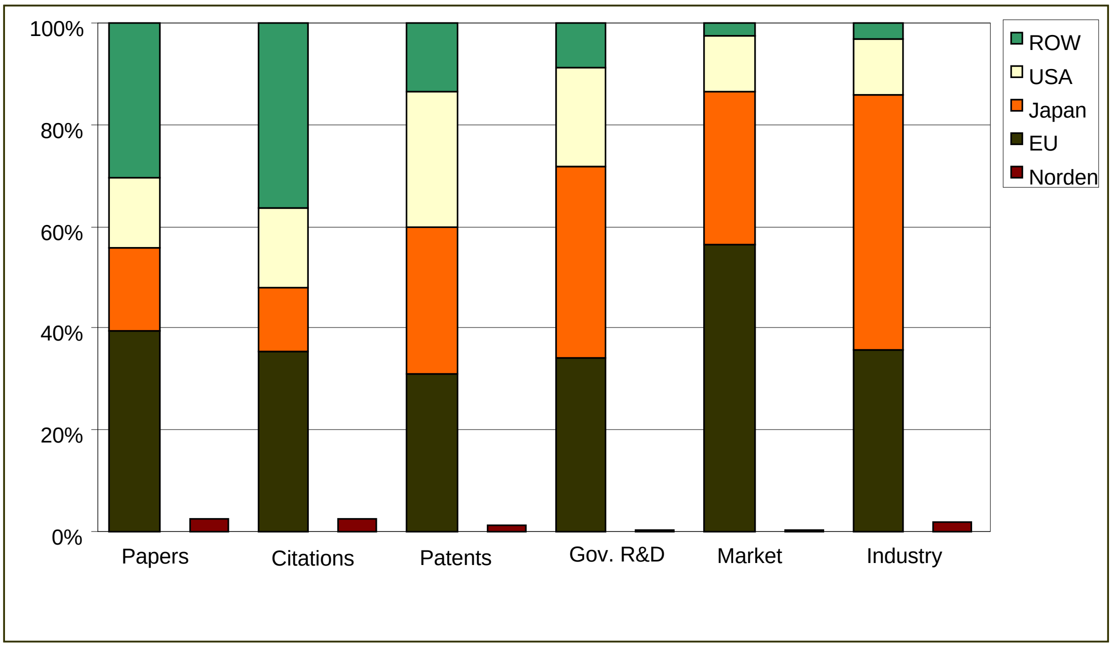
Primary source:

- International Wind Energy Development – World Market Update 2006 – Forecast 2007-2011, BTM Consult ApS – March 2007. I. C. Christensens Allé 1, Ringkøbing, DK. BTM Consult, www.btm.dk

The increasing internationalization and outsourcing of the industrial manufacturing of wind turbines makes difficult to define suppliers based on national records where large firms are ascribed. For instance, the firm Nordex started out as a Danish family owned firm, but is today controlled by German interests with manufacturing facilities in two different places in Germany and with subsidiaries in several countries.

The data covers figures globally, and they are updated by the end of 2006. However, the BTM report is annual and a separated report includes detail analyses of certain areas such as supply and demand chains, which seems relevant for an indicator of industry formation. This part of the report was not consulted due the frames allowed for this study.

B.2 Solar Cells (Photovoltaics)



	Papers	Citations	Patents	Gov. R&D	Market	Industry
Period	*1996-2006*	*1996-2006*	*1996-2006*	*1996-2005*	*2006*	*2006*
Unit	*Number*	*number*	*number*	*Million €*	*MWp*	*MW*
EU	2480	10021	670	757.7	3200	654
Japan	1044	3479	621	831.4	1709	920
USA	858	4422	574	431.6	624	201
ROW	1917	10256	293	191.2	147	59
Total	6299	28178	2158	2211.9	5680	1834
Of which						
Denmark	21	83	4	12.5	2.9	0
Finland	25	149	4	No data	(4.1)	No data
Iceland	0	0	0	No data	No data	No data
Norway	8	22	6	2.0	7.6	37
Sweden	110	441	13	3.0	4.8	0
Norden	164	695	27	17	16.5	37

Definitions and sources:

- **Papers and Citations**: Include those listed in the Science Citation Index. The search string used for the search is: '(photovoltaic# and (cell# or power or energy or conversion)/ti or (solar cell#)/ti'.
- **Patents:** Includes patents listed in Derwent World Patents Index. The search string used for the search is: '(photovoltaic# and (cell# or power or energy or conversion)/ti or (solar cell#)/ti'.
- **Governmental R&D expenditure**: is defined by IEA as government energy technology R&D budgets in million Euro (2005 prices and exchange rates). ROW here only includes IEA member countries.
- **Market indicator is** defined as accumulated installed capacity of PV measured in MWp by the end of 2006. Source: IEA-PVPS *Trends in Photovoltaic applications – Survey Report of selected IEA countries between 1992 and 2006 - IEA 2007*. Data for Finland is based on EurObserv'er 2007: http://www.energies-renouvelables.org/observ-er/stat_baro/observ/baro172.pdf
- **Industry indicator** is defined as PV cell production in MW during 2006 by a country or regions Source: http://www.iea-pvps.org/. This indicator does not take not into account supplying industries. - IEA Photovoltaic Power Systems. Norway is the only Nordic country included in this dataset. For the other Nordic countries, see http://www.iea-pvps.org/ under national surveys and reports.

B.2.1 General comments

B.2.2 Publications, citations and patents

Bibliometric searches are carried out for publications and citations in Science Citation Index (Web of Science) and Derwent World Patents Index (patents). Both of which are hosted online via STN International. In all three cases the search counts authors of the selected articles distributed over the selected countries or groups of countries (e.g. EU). A single publication with co-authors from both Germany, USA and Japan will count for all three countries.

Values comprise cumulated figures for the time span of 1996-2006.

The search strings used for this report are the following:

- Science citation index: (photovoltaic# and (cell# or power or energy or conversion)/ti or (solar cell#)/ti
- Derwent world patents index: (photovoltaic# and (cell# or power or energy or conversion)/ti or (solar cell#)/ti

The key quality issue concerns the selection of search strings and exclusion of articles, citations, and patents irrelevant for the specific task. Concerning the latter issue no efforts have been taken to exclude "false" data except adjusting search words.

b.2.3 Governmental R&D expenditures

This indicator includes Government energy technology R&D budgets. For photovoltaics the data includes data for concerning the following issues: Solar cell development; PV module development; PV-inverter development; building-integrated PV-modules; PV-system development; and other.

The data is downloaded from IEAs' "Access Database (2006 Edition)". See: http://www.iea.org/Textbase/stats/rd.asp

Data is available since the 1970s. The indicators here are cumulated figures for the years 1996 to 2005. Limitations and uncertainties are affiliated with data since 2001, 2002 or 2003 are not available from several countries; among others France and the US. No data at all has been reported for Finland. Figures are listed in Million Euro (2005 prices and exchange rates). Consequently, the quality of data on photovoltaics is in general quite poor.

A general assessment of the quality of the data can be found in:

- Energy R&D Statistics in the European Research Area. Final Report (2005) Directorate-General for Research, Sustainable Energy Systems, EUR 21453. ISBN 92-894-8964-2

A secondary source on governmental R&D expenditures can be found at the web site of IEA's implementation agreement on PV. See Table B.2.1.

	Annual Budget in million EUR and million USD (2006)								
	Country	R&D		Demonstration and field trials		Market stimulation		Total	
		EUR	USD	EUR	USD	EUR	USD	EUR	USD
EU	AUS	4,2	5,2	0,4	0,5	14,2	17,8	18,8	23,5
EU	DEU	66	82,5	*(included in R&D)*				..	..
EU	DNK	6,7	8,4	2,5	3,2	0,1	0,1	5,8	7,3
EU	FRA	26,2	32,8	0,2	0,2	1,8	2,3	11,5	14,4
EU	GBR	10,6	13,3	-	-			..	..
EU	ITA	4,8	6	0,7	0,8	-	-	7,4	9,2
EU	NLD	9,4	11,7	-	-	20	25	46,2	57,8
EU	SWE	1,5	1,9	11,6	14,5	-	-	22,2	27,8
Japan	JPN	21,8	27,2	-	-	-	-	0,1	0,1
ROW	AUT	1,3	1,6	0,2	0,3	6	7,5	11	13,8
ROW	CAN	3,2	4,0	93,5	116,9	28,5	35,7	143,8	179,8
ROW	CHE	9,5	11,9	0,2	0,3	81,3	101,6	97,3	121,6
ROW	ISR	0,1	0,1	0,7	0,9	-	-	1,5	1,9
ROW	KOR	15,8	19,7	-	-	3	3,8	12,4	15,5
ROW	MEX	0,8	1	-	-	-	-	1,7	2,1
ROW	NOR	1,7	2,1	-	-	0,7	0,9	2,2	2,8
USA	USA	97,4	121,8	2,4	3,0	352,0	440,0	451,8	564,8

Table B.2.1. Public budget for R&D, demonstration & field trials and market stimulation in 2006 for Photovoltaics. Source:Table downloaded from the IEA-PVPS website, http://www.iea-pvps.org

B.2.4 Market indicator

The market indicator is defined as accumulated installed capacity of PV measured in MWp as of the end of 2006.

Primary source:

- IEA-PVPS Trends in Photovoltaic applications – Survey Report of selected IEA countries between 1992 and 2006 - IEA 2007. Downloaded from the IEA-PVPS website, http://www.iea-pvps.org with the IEA Photovoltaic Power Systems Programme.

The IEA database has no data for Finland and Iceland. Therefore, data for Finland is based on the secondary source:

- Barometers EurObserv'ER's Photovoltaic Energy Barometer 2007: http://www.energies-renouvelables.org/observ-er/stat_baro/observ/baro172.pdf

Figures from IEA and EurObserv'ER are not identical for the European countries. As IEA only include countries member of both EU and the IEA's implementing agreement on PV. Whereas, EurObserv'ER include figures from all EU members. But the differences do not disturb the overall picture.

Of the total capacity installed in the IEA PVPS countries during 2006 about 4 % (63 MW) were installed in off-grid projects. The types of off-grid applications vary between markets. For example, in the Nordic countries the most common off-grid applications are for vacation cottages, whilst in Australia, Canada and Mexico providing cost effective rural electrification tends to be the main aim. In these markets, telecommunication and infrastructure applications are also important.

B.2.5 Industry indicator

The industry indicator is defined as PV cell production in MW during 2006. The industry indicator for PV faces two challenges: 1) Data is not detailed 2) just a few actors in the manufacturing processes are taken into account by the sources.

Primary source:

- IEA-PVPS Trends in Photovoltaic applications – Survey Report of selected IEA countries between 1992 and 2006 - IEA 2007. Downloaded from the IEA-PVPS website, http://www.iea-pvps.org with the IEA Photovoltaic Power Systems Programme.

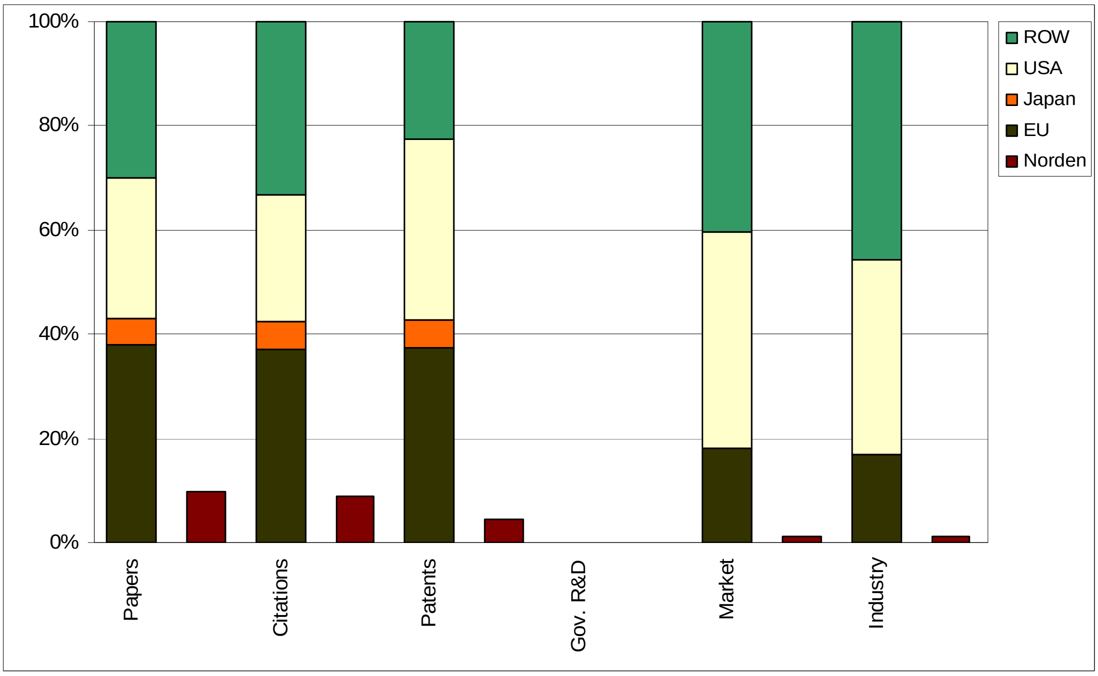
Only cell production in Norway is included in the IEA figures. Figures for other Nordic countries are estimated through alternative sources; namely the annual national surveys and reports of IEA-PVPS. http://www.iea-pvps.org.

According the IEA-PVPS 2007 annual report for Denmark PV Si cell production stopped in Denmark in 1996. A single Danish module manufacturer (Gaia Solar) with an annual capacity of about 0.5 MW per shift has existed since 1996. New business developments are observed by the annual report in the fields of Si feed stock and inverters. An increase from 40 MEUR in 2006 to 45 MEUR in 2007 is a "best guess" of the total PV related turnover in Denmark - mostly due to exports.

According the IEA-PVPS 2007 annual report for Sweden the Swedish PV industry has grown significantly over the last couple of years. Today, five companies produce PV modules. All of them buy cells from abroad and assemble modules, which to a large extent are exported. The firms are: Gällivare PhotoVoltaic AB, ArcticSolar AB, n67 Solar AB, PV Enterprise Sweden AB and finally ScanModule AB, which is a subsidiary of the Norwegian Renewable Energy Corporation (REC). In 2006 ScanModule AB was the largest module manufacturer in Sweden; with 160 employees.

Hence, if our indicator included both modules and converters, the Nordic countries had probably had a more visible part of the global industrial activities based on PV. Still, the Nordic PV industry is dwarfed by activities in other parts of the World.

B.3 Biofuel

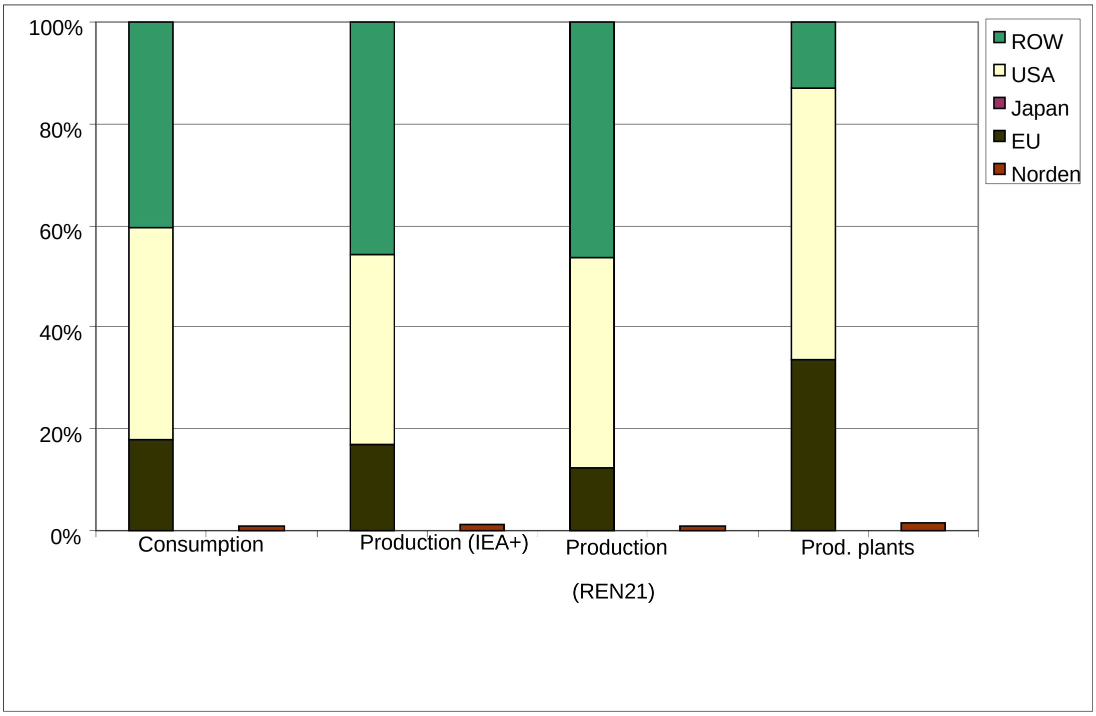


	Papers	Citations	Patents	Gov. R&D	Market	Industry
Period	*1996-06*	*1996-06*	*1996-06*	*1996-05*	*2006*	*2006*
Unit	*Number*	*Number*	*Number*	*Million €*	*Consumption (kiloton)*	*Production (kiloto)*
EU	673	2.548	195	-	7624	7178
Japan	89	365	29	No data	0	No data
USA	477	1.673	181	No data	17585	15799
ROW*	533	2.285	118	-	17120	19317
Total	1772	6871	523	-	42329**	42294**
Of which						
Denmark	27	132	9	7.2	6	71
Finland	37	119	6	No data	7	7
Iceland	0	4	0	No data	No data	No data
Norway	4	24	0	0.2	No data	No data
Sweden	103	339	8	29.3	434	434
Norden	171	618	23	-	441	512

Definitions and sources:

- **Papers and Citations**: Include only those listed in the Science Citation Index. The search string used for the search is: '(biofuel? or bio fuel? or biodiesel or bio diesel or biomass fuel? or bioethanol or bio ethanol)/ti,st or (biomass and (ethanol or diesel))/ti,st'
- **Patents:** Includes patents listed in Derwent World Patents Index. The search string used for the search is: '(biofuel? Or bio fuel? Or biodiesel or bio diesel or biomass fuel? Or bioethanol or bio ethanol or biomass ethanol or biomass diesel) and H06/dc or (biofuel? Or bio fuel? Or biodiesel or bio diesel or biomass fuel? Or bioethanol or bio ethanol or biomass ethanol or biomass diesel)/ti'.
- **Governmental R&D expenditure**: is defined by IEA as government energy technology R&D budgets in million Euro (2005 prices and exchange rates). ROW: only IEA member countries.
- **Market indicator** is defined as the gross consumption of liquid biomass, Source 1: IEA Renewables Information (2007). Source 2: ROW includes IEA/OECD countries added figures for Brazil, India and China: FAPRI 2007 U.S. and World Agricultural Outlook, January 2007.
- **Industry indicator** is defined as the production of liquid biomass (in kiloton) in 2006. Source: IEA Renewables Information (2007). *) ROW added the ethanol production in Brazil, China, India, Russia and South Africa Source: *Renewable Fuels Association.* **) Totals are estimates based on different sources. Exact figures cannot be compared.

Alternative indicators for the Industry indicators



		Market	Industry 1	Industry 2	Industry 3
Period		*2006*	*2006*	*2005*	*2006*
Unit		*Consumption (kiloton)*	*Production (kiloton)*	*Production (bn liters)*	*Number of production plants*
EU		7624	7178	4.5	109
Japan		0	No data	0	0
USA		17585	15799	15.3	174
ROW		17120	19317	17.0	42
Total		42329	42294	36.8	325
Of which					
Denmark		6	71	0.1	2
Finland		7	7	No data	0
Iceland		No data	No data	No data	0
Norway		No data	No data	No data	0
Sweden		434	434	0.2	3
Norden		441	512	0.3	5

Definitions and sources:

- **Market indicator** is defined as the gross consumption of liquid biomass, Source 1: IEA Renewables Information (2007). Source 2: ROW includes IEA/OECD countries added figures for Brazil, India and China: FAPRI 2007 U.S. and World Agricultural Outlook, January 2007.
- **Industry indicator 1** is defined as the production of liquid biomass (in kiloton) in 2006. Source: IEA Renewables Information (2007). *) ROW added the ethanol production in Brazil, China, India, Russia and South Africa (Source: *Renewable Fuels Association http://www.ethanolrfa.org/industry/statistics/#B*).
- **Industry indicator 2:** Production in billion of liters. Source: *Renewables Global Status Report – 2006 Updated*. Table 6 page 22.
- **Industry indicator 3:** Number of plants of major biofuel manufactures in the world in 2006. Source: www.biofuelsmarketplace.com

B.3.1 Introduction

In most international statistics the term biofuels primarily cover liquid biofuels such as bioethanol and biodiesel. These two fuels account for the overwhelming majority of all liquid biofuels produced and used globally.

There is an abundance of data related to installed capacity and manufacturing of biofuels. However, there are no comparable, reliable and publicly available data on the total amount of machinery and technological equipment, components and devices used in the biorefineries producing these biofuels. Due to this constrained we suggest to consider this total consumption of bio fuel as a proxy for the market indicator and the total production of biofuel as a proxy for the industry indicator.

B.3.2 Publications, citations and patents

Bibliometric searches are carried out for publications and citations in Science Citation Index (Web of Science) and Derwent World Patents Index (patents). Both of which are hosted online via STN International. In all three cases the search counts authors of the selected articles distributed over the selected countries or groups of countries (e.g. EU). A single publication with co-authors from both Germany, USA and Japan will count for all three countries.

Values comprise cumulated figures for the time span of 1996-2006.

The search strings used for this report are the following:

- Science citation index: (biofuel? or bio fuel? or biodiesel or bio diesel or biomass fuel? or bioethanol or bio ethanol)/ti,st or (biomass and (ethanol or diesel))/ti,st
- Derwent world patents index: (biofuel? Or bio fuel? Or biodiesel or bio diesel or biomass fuel? Or bioethanol or bio ethanol or biomass ethanol or biomass diesel) and H06/dc or (biofuel? Or bio fuel? Or biodiesel or bio diesel or biomass fuel? Or bioethanol or bio ethanol or biomass ethanol or biomass diesel)/ti

The key quality issue concerns the selection of search strings and exclusion of articles, citations, and patents irrelevant for the specific task. Concerning the latter issue no efforts have been taken to exclude "false" data except adjusting search words.

B.3.3 Governmental R&D expenditures

This indicator includes Government Energy Technology R&D Budgets. For bio fuel the data includes following issues: conventional bio-fuels; cellulosic conversion to alcohol; biomass gas-to-liquids; and other.

Figures are listed in Million Euro (2005 prices and exchange rates).

The data is downloaded from IEAs' "Access Database (2006 Edition)". See: http://www.iea.org/Textbase/stats/rd.asp

Data is available only since the 2004. Limitations are affiliated with data missing from many countries; among others large key players such as Finland, France and United States.

In general the quality of data on bio fuel is quite poor.

A general assessment of the data can be found in this reference:

- Energy R&D Statistics in the European Research Area. Final Report (2005) Directorate-General for Research, Sustainable Energy Systems, EUR 21453. ISBN 92-894-8964-2

B.3.4 Market indicator - Gross consumption of biofuel

This study is about innovation in energy technologies. For bio fuel the challenge is that no market surveys are available for equipment producing bio fuels. Instead the bio fuel itself must be object of analysis. The idea is that the gross consumption of biofuel can act as a proxy for the market for bio energy technologies.

Primary source for this indicator is:

- o IEA Statistics, Renewable Information 2007. ISBN 978-92-64-02775-6. International Energy Agency, 2007. International Energy Agency (IEA), Paris, France.

IEA statistics use the term 'liquid biomass' that cover fuels and bioadditives such as biogasoline (bioethanol, biomethanol, biomethylether, etc.) biodiesel an dother liquid fractions. Gross consumption of bio fuel is here defined as the consumption of liquid biomass, which is made up of production, plus net imports ± stock changes – transfers. Liquid biomass include different liquids. In general bio ethanol is the largest component globally but bio diesel is the most dominant in Europe. The IEA data only include figures for IEA/OECD member countries.

An alternative source is:
- o FAPRI 2007 U.S. and World Agricultural Outlook, January 2007, FAPRI Staff Report 07-FSR 1, ISSN 1534-4533, Chapter World Biofuels, pp317-320.
  http://www.fapri.iastate.edu/outlook2007/text/OutlookPub2007.pdf

FAPRI (Food and Agricultural Policy Research Institute) is funded the U.S. Congress, and located at Iowa State University and the Center for National Food and Agricultural Policy (CNFAP) at the University of Missouri-Columbia. The table below stems from this report. The consumption of bio diesel in US and Europe is assumed to equal the production. In this source production is expressed in US Gallons.
- o 1 Gallon = 3.785 Litre or 0.003785 Cubic Metre (m^3)

Bio ethanol and bio diesel have slightly different density.
- o Density of biodiesel: 0.840 kg/litre or tonnes/m^3
- o Density of bioethanol: 0.789 kg/litre or tonnes/m^3

	Production in 2006			Consumption in 2006		
	Mill gallon		kiloton	Mill gallon		kiloton
	Bioethanol	Biodiesel	Total	Bioethanol	Biodiesel	Total
US	4856	385	16589	5370	385*	18223
EU-25	864	5504	19184	935	5504*	19410
Brazil	4763	n.a.	15143	3648	n.a.	11598
China	1083	n.a.	3443	1041	n.a.	3310
India	486	n.a.	1545	604	n.a.	1920

Table 1 Production and consumption of bioethanol and biodiesel in selected countries. Source: FAPRI 2007 U.S. and World Agricultural Outlook, January 2007, FAPRI Staff Report 07-FSR 1, ISSN 1534-4533, Chapter World Biofuel. See text for conversion of units.) no data available for consumption but anticipated to equal production.*

The resulting figures slightly differ from the IEA data. But the point here is to estimate the Nordic countries' share of the global figures and not to give an exact figure for each country.

B.3.5 Industry indicator (production of biofuel)

As mentioned above the production of biofuel is used as a proxy for the industry indicator. Following this the industry indicator is defined as the production of liquid biomass (in kiloton) in 2006.

Primary source for information for this indicator is:
- o IEA Statistics, Renewable Information 2007. ISBN 978-92-64-02775-6. International Energy Agency, 2007. International Energy Agency (IEA), Paris, France.

As only data from IEA member countries is included in this source data for ROW (Rest of the World) is added the ethanol production in Brazil, China, India, Russia and South Africa. These four countries account for 47% of the global ethanol production.

Secondary source for this is:
- o Industry Statistics, Renewable Fuels Association http://www.ethanolrfa.org/industry/statistics/#B).

For illustrative purposes, it can be noted that data concentrating on production of biofuels in Denmark and Sweden reveal that these countries are the main players in the Nordic region. Although, Finland's share of biofuel in its renewable energy consumption is high, it is up to a great extent dependent on imports. These types of pitfalls of the indicator are corrected by adding the gross consumption instead of manufacturing.

'Two further indicators have been investigated for the industrial production.

Alternative industry indicator 2:

- Biofuel (Fuel ethanol and bio diesel) production in billion of liters. Source: Renewables Global Status Report – 2006 Updated. Table T6, page 39.

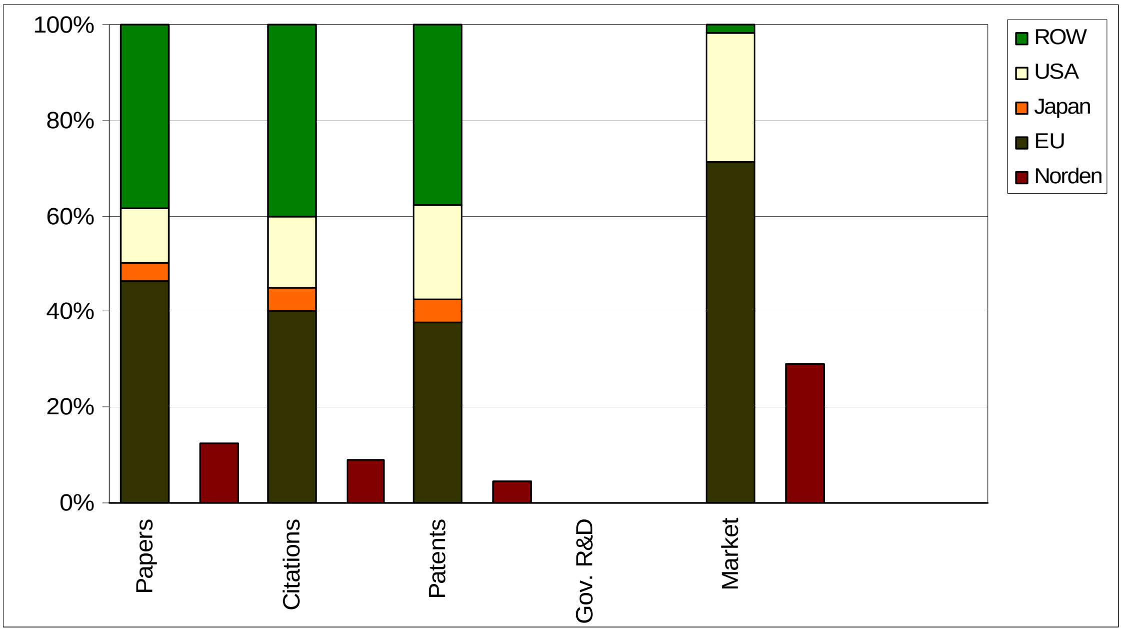
This source notes that only figures for fuel ethanol are included, total production figures will be significantly higher.

Alternative industry indicator 3:

- Number of plants of major biofuel manufactures in the world in 2006. Source: www.biofuelsmarketplace.com.

The industry indicator can be enriched with more information from F. O. Licht. However, F. O. Licht includes all types of alcohol (potable, synthetic, biomass-derived) of a variety of values and grades and for several purposes. It represents the same problem as accounts or data of biorefineries that produces different types of alcohol like beverage alcohol such as alcoholic spirits, vodka, etc., industrial alcohol that focuses on e.g. cosmetics, paints and inks and fuel alcohol, which can be blended or used in pure form.

B.4 Biomass for Heat and Power



	Papers	Citations	Patents	Gov. R&D	Market	Industry
Period	*1996-2006*	*1996-2006*	*1996-2006*	*2004-2005*	*2006*	
Unit	*number*	*number*	*number*	*Million €*	*TJ*	
EU	1471	4781	885	Limited data	352782	
Japan	124	582	114	No data	0	
USA	366	1779	462	No data	134370	
ROW	1219	4792	885	Limited data	8384	
Total	3180	11934	2346	-	495537	
Of which						
Denmark	112	271	44	12.6	39632	
Finland	61	214	26	No data	35557	
Iceland	2	2	3	No data	0	
Norway	13	55	17	1,6	1701	
Sweden	206	515	15	3.0	66843	
Norden	394	1057	105	17	143733	

Definitions and sources:

- **Papers and Citations**: Include only those listed in the Science Citation Index. The search string used for the search is: '(biomass and (energy or heat? or combust? or power) not (hydrogen or bioethanol or bio ethanol or biofuel?)) and (energy? or agricultural(w)engineering)/cc or biogas'.
- **Patents:** Includes patents listed in Derwent World Patents Index. The search string used for the search is: '((biomass and (energy or heat? or combust? or power) not (hydrogen or bioethanol or bio ethanol or biofuel?)) or X15-E/mc or biogas'.
- **Governmental R&D expenditure**: Not included due to missing data from key actors such as USA and Finland.
- **Market indicator** is defined as the production of electricity and heat based on biomass (Wood, Wood-waste, Municipal waste, Biogas) in TJ during 2006. Source: IEA Renewable Information, 2007. Figures only include IEA/OECD member countries.
- **Industry indicator** – no suitable data available.

B.4.1 Introduction

B.4.2 Publications, citations and patents

Bibliometric searches are carried out for publications and citations in Science Citation Index (Web of Science) and Derwent World Patents Index (patents). Both of which are hosted online via STN International. In all three cases the search counts authors of the selected articles distributed over the selected countries or groups of countries (e.g. EU). A single publication with co-authors from Germany, USA and Japan will count for all three countries.

Values comprise cumulated figures for the time span of 1996-2006.

The search strings used for this report are the following:

- Science citation index: (biomass and (energy or heat? or combust? or power) not (hydrogen or bioethanol or bio ethanol or biofuel?)) and (energy? or agricultural(w)engineering)/cc or biogas
- Derwent world patents index: ((biomass and (energy or heat? or combust? or power) not (hydrogen or bioethanol or bio ethanol or biofuel?)) or X15-E/mc or biogas

The key quality issue concerns the selection of search strings and exclusion of articles, citations, and patents irrelevant for the specific task. Concerning the latter issue no efforts have been taken to exclude “false” data except adjusting search words.

B.4.3 Governmental R&D expenditures

This indicator includes Government Energy Technology R&D Budgets. For bio mass’ application for heat and electricitythe data includes following issues: Bio-heat excluding multifiring with fossil fuels; bio-electricity excluding multifiring with fossil fuels; CHP (combined heat and power) excluding multifiring with fossil fuels; recycling and uses of urban, industrial and agricultural wastes not covered elsewhere.
Figures are listed in Million Euro (2005 prices and exchange rates).
The data is downloaded from IEAs’ “Access Database (2006 Edition)”. See:
http://www.iea.org/Textbase/stats/rd.asp

Data is available only since the 2004. Limitations are affiliated with data missing from many countries; among others large countries such as Japan and United States. Also, figures on Finland are absent.
In general the quality of data on bio fuel is quite poor.

A general assessment of the data can be found in this reference:

- Energy R&D Statistics in the European Research Area. Final Report (2005) Directorate-General for Research, Sustainable Energy Systems, EUR 21453. ISBN 92-894-8964-2

B.4.4 Market indicator (production of biomass based heat and electricity)

As for the market indicator biofuel production technology no data is available for the market for equipment for producing heat and power based on biomass. Instead of technology we use the production of energy (heat and electricity) based on biomass.

The market indicator is defined as biomass based electricity and heat produced in TJ produced during 2006 by a country or regions using renewable resources.

Primary source:

- IEA Statistics, Renewable Information 2007, ISBN 978-92-64-02775-6, International Energy Agency, 2007

Data from IEA was corroborated and it matches almost entirely with national surveys. Hence, the data presented seems be reliable. However, more emphasis can be done by differentiating the type of energy source used to produce electricity and heat, whereas it is solid biomass or industrial waste.

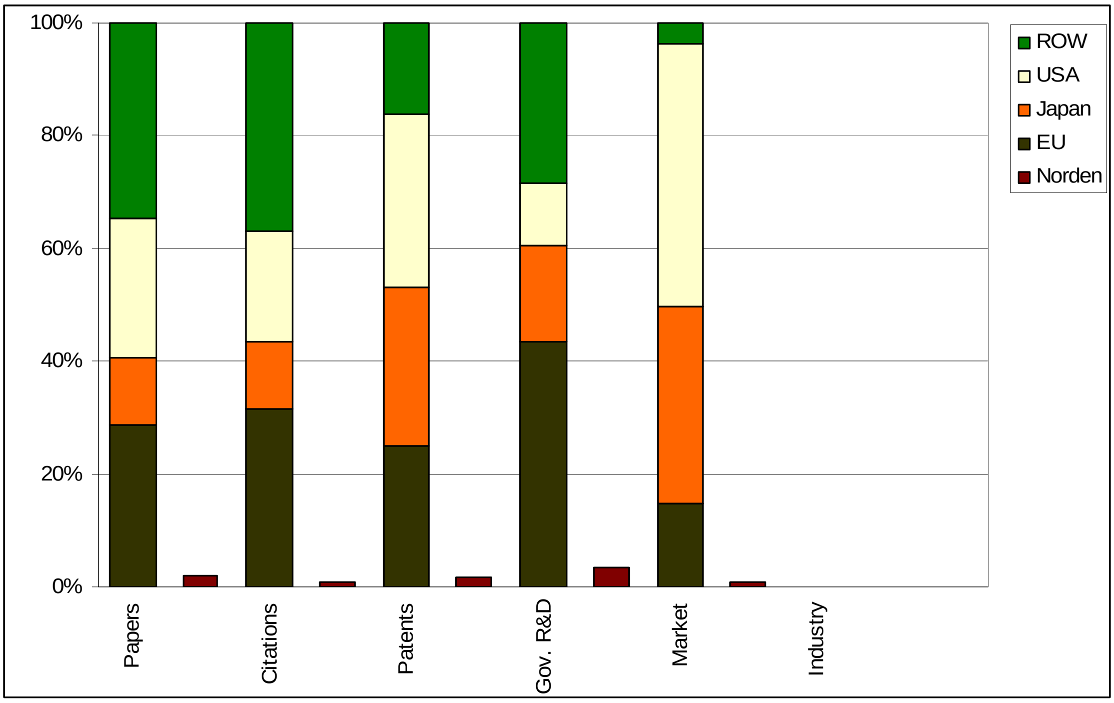
It seems that the account of renewables made by IEA is consistent and aware of this differentiation. However, as it is stipulated by IEA’s Renewable Information (2007) there is a potential problem with the breakdown between renewable municipal waste and non-renewable municipal waste.

The data covers biomass-based heat and power production in IEA countries. Rest of the world in this case only comprise IEA member countries.

B.4.5 Industry indicator

No suitable indicator for industry can be established.

B.5 Fuel Cells



	Papers	Citations	Patents	Gov. R&D	Market	Industry
Period	*1996-2006*	*1996-2006*	*1996-2006*	*2004-2005*	*2005*	*2006*
Unit	*Number*	*Number*	*Number*	*M €*	Installed capacity (kW)	
EU	2513	7598	3119	(138)	16851	
Japan	1037	2915	3478	No data	40101	
USA	2161	4748	3839	119	52908	
ROW	3015	8916	2012	Limited data	4373	
Total	8726	24177	12448	-	114235	
Of which						
Denmark	80	287	44	21.3	200	
Finland	40	116	13	No data	200	
Iceland	3	4	0	No data	10	
Norway	46	165	12	1.5	250	
Sweden	161	337	26	1.9	260	
Norden	330	909	95	Limited data	920	

Definitions and sources:

- **Papers and Citations**: Include only those listed in the Science Citation Index. The search string used for the search is: 'fuel cell#/ti,st'.
- **Patents:** Includes patents listed in Derwent World Patents Index hosted by STN International. The search string used for the search is: 'fuel cell#/ti'.
- **Governmental R&D expenditure**: is defined by IEA as government energy technology R&D budgets in million Euro (2006 prices and exchange rates). EU figure lack data from several countries but include data from large countries such as Germany, France and UK.
- **Market indicator** is based on rough estimates of projects ongoing, operational, planned, decommissioned, tested, demonstrated and scheduled before the year 2005 and measured in kilowatts. Source: Update October, 2005 of Fuel Cell 2000. The data does not take into account fuel cell systems for vehicles. http://www.fuelcells.org/info/charts/FCInstallationChart.pdf.
- **Industry indicator:** No globally comparable and reliable data can be found.

B.5.1 Introduction

Fuel cells cover a wide-range of applications and types of basic technology and depending on the state-of-the-art and efficiency fuel cells will be prone to play a major role in the future market of renewable energy technologies. In a context of innovation and needs integration the area of fuel cells can be approached in three categories:

- Fuel cells is electric power generation is by far the largest category today.
- Fuel cells used to power portable electronic (laptops, mobile phones, etc.) is the most rapid increasing category as the technological development of fuel cells increasingly makes them outperforming most types of batteries used for similar purposes.
- Fuel cell for the motor vehicles is a third category. This category continues to delay widespread commercialization. Market presence of gasoline-electric hybrid vehicles and all-electric vehicles probably also restrains growth in the category.

B.5.2 Publications, citations and patents

Bibliometric searches are carried out for publications and citations in Science Citation Index (Web of Science) and Derwent World Patents Index (patents). Both of which are hosted online via STN International. In all three cases the search counts authors of the selected articles distributed over the selected countries or groups of countries (e.g. EU). A single publication with co-authors from Germany, USA and Japan will count for all three countries.

Values comprise cumulated figures for the time span of 1996-2006.

The search strings used for this report are the following:

- Science citation index: (hydrogen fuel? or hydrogen production or hydrogen energy or hydrogen power?) or (hydrogen and (economy or society or storage))/ti
- Derwent world patents index: (hydrogen fuel? or hydogen production or hydrogen energy or hydrogen power? or hydrogen storage)/ti

The key quality issue concerns the selection of search strings and exclusion of articles, citations, and patents irrelevant for the specific task. Concerning the latter issue no efforts have been taken to exclude "false" data except adjusting search words.

B.5.3 Governmental R&D expenditures

This indicator includes Government energy technology R&D budgets. For fuel cells data includes all three categories: Stationary Applications; Mobile Applications; and Other Applications (Portable applications).

The data is downloaded from IEAs' "Access Database (2006 Edition)". See:
http://www.iea.org/Textbase/stats/rd.asp

Data is available since 2004. Limitations are affiliated with data lacking for key countries such as Finland, France and Japan. The indicators here are cumulated figures for the years 2004 to 2005.

Figures are listed in Million Euro (2006 (sic!) prices and exchange rates.

In general the quality of data on hydrogen is poor due to lack of data for many countries. EU figure lack data from several countries but include data from the three large countries Germany, France and UK.

A general assessment of the quality of the data can be found in:

- Energy R&D Statistics in the European Research Area. Final Report (2005) Directorate-General for Research, Sustainable Energy Systems, EUR 21453. ISBN 92-894-8964-2

B.5.4 Market indicator

The market indicator is approached by counting demonstration projects and decommissioned installations. The indicator is defined as projects (ongoing, operational, planned, decommissioned, tested, and demonstrated) before the year 2005 and measured in kilowatts.

Primary source for this indicator was

- o Fuel Cell 2000 – Update of October 2005, available through http://www.fuelcells.org/info/charts/FCInstallationChart.pdf

This source does not take into account fuel cell systems for vehicles.

Secondary sources:

- o www.fuelcelltoday.com. The quality of the data is poor in this context, as they are mostly based on voluntary reports made by some countries. Furthermore, projects within the USA might be overrepresented as the organization is based on the USA.

- o Fuel cell markets, available through: http://www.fuelcellmarkets.com/fuel_cell_markets/industry/2,1,1,7.html. The data does not take into account fuel cell systems for vehicles or portable fuel cells.

- o Data on vehicles, special vehicles, and busses can be obtained from:
    - o http://www.fuelcells.org/info/charts/specialty.pdf
    - o http://www.fuelcells.org/info/charts/carchart.pdf
    - o http://www.fuelcells.org/info/charts/buses.pdf

In general the data is very weak in accounting fuel cell installations in the developing world.

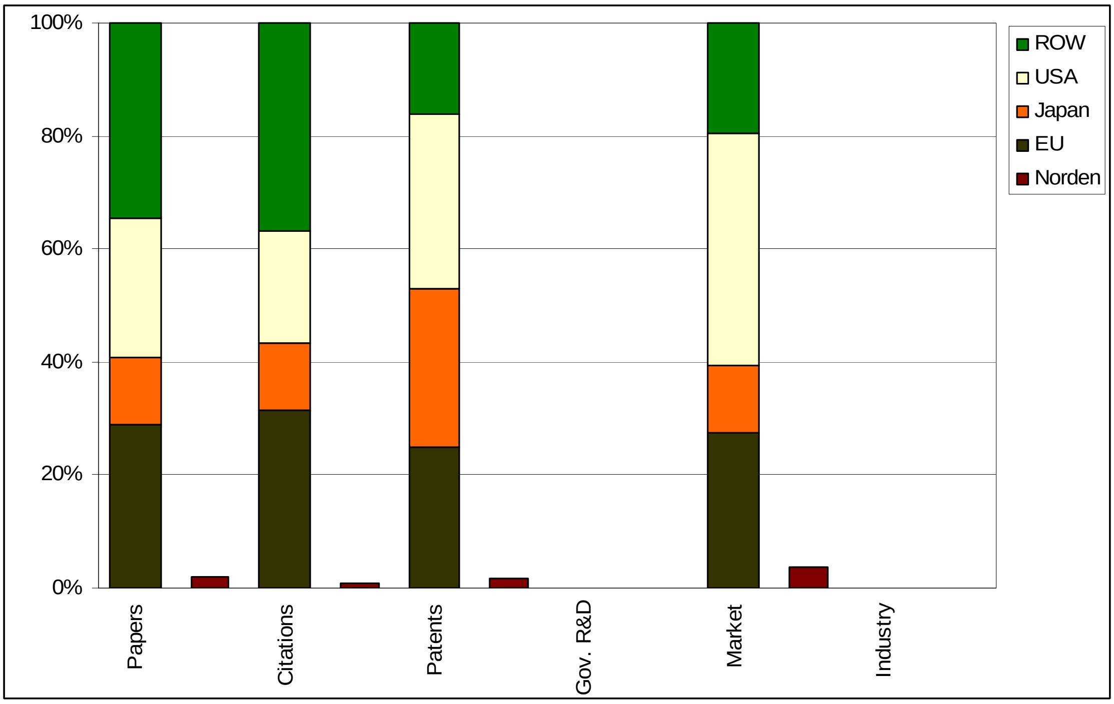
B.5.5 Industry indicator

No globally comparable and reliable data can be found. Like discussed for wind turbines and PV the industrial production of fuel cell systems could be a comparable indicator. But ideally also the manufacturing of fuel cells stacks and other components should be included.

An indicator of the industrial activity could be assessed by counting the number of companies involved in the fuel cell industry without regarding their market share.

This data can be obtained from internet sources (e.g. fuelcellstoday.com).

B.6 Hydrogen



	Papers	Citations	Patents	Gov. R&D	Market	Industry
Period	*1996-2006*	*1996-2006*	*1996-2006*	*2004-2005*	*2008*	
Unit	*Number*	*Number*	*Number*	*Million €*	No. of filling stations	
EU	567	4294	139	Limited data	45	
Japan	461	2306	199	No data	19	
USA	631	2788	337	142	67	
ROW	1380	6237	303	Limited data	32	
Total	3039	15625	978	-	163	
Of which						
Denmark	13	85	2	2.5	2	
Finland	3	34	1	No data	0	
Iceland	3	4	0	No data	1	
Norway	19	133	3	9.2	2	
Sweden	23	165	4	3.1	1	
Norden	61	421	10	No data	6	

Definitions and sources:

- **Papers and Citations**: Include those listed in the Science Citation Index. The search string used for the search is: 'hydrogen fuel? or hydrogen production or hydrogen energy or hydrogen power?) or (hydrogen and (economy or society or storage))/ti'.
- **Patents:** Includes patents listed in Derwent World Patents Index. The search string used is: '(hydrogen fuel? or hydrogen production or hydrogen energy or hydrogen power? or hydrogen storage)/ti'.
- **Governmental R&D expenditure**: is defined by IEA as government energy technology R&D budgets in million Euro (2005 prices and exchange rates). ROW here only includes IEA member countries. Figures are missing from key countries such as Japan, USA, and Finland.
- **Market indicator** is defined as the number of H2 filling stations in operation. Source: http://www.netinform.net/h2/H2Stations/Default.aspx. Figures are estimated.
- **Industry indicator** – no globally comparable and reliable information is available.

B.6.1 Introduction

Hydrogen production is difficult to measure due to the fact that hydrogen is merely produced for petrochemical processes. It is uncertain how much hydrogen based on renewable sources is produced uniquely for transportation and the production of electricity, heat and cooling systems. Hydrogen production from reforming processes is the most common, while biomass-based hydrogen production seems to be in an up-coming stage.

B.6.2 Publications, citations and patents

Bibliometric searches are carried out for publications and citations in Science Citation Index (Web of Science) and Derwent World Patents Index (patents). Both of which are hosted online via STN International. In all three cases the search counts authors of the selected articles distributed over the selected countries or groups of countries (e.g. EU). A single publication with co-authors from Germany, USA and Japan will count for all three countries.

Values comprise cumulated figures for the time span of 1996-2006.

The search strings used for this report are the following:

- o Science citation index: (hydrogen fuel? or hydrogen production or hydrogen energy or hydrogen power?) or (hydrogen and (economy or society or storage))/ti
- o Derwent world patents index: (hydrogen fuel? or hydogen production or hydrogen energy or hydrogen power? or hydrogen storage)/ti

The key quality issue concerns the selection of search strings and exclusion of articles, citations, and patents irrelevant for the specific task. Concerning the latter issue no efforts have been taken to exclude "false" data except adjusting search words.

B.6.3 Governmental R&D expenditures

This indicator includes Government energy technology R&D budgets. For hydrogen energy he data includes data for concerning the following issues: Production; Storage; Transport and Distribution; Other Infrastructure and Systems R&D (Including refuelling stations for hydrogen-fuelled cars); and End Uses (including combustion; excluding fuel cells).

The data is downloaded from IEAs' "Access Database (2006 Edition)". See: http://www.iea.org/Textbase/stats/rd.asp

Data is available since 2004. Limitations are affiliated with data lacking for key countries such as Finland, France and Japan. The indicators here are cumulated figures for the years 2004 to 2005.

Figures are listed in Million Euro (2005 prices and exchange rates).

In general the quality of data on hydrogen is among the less reliable due to lack of data for many countries.

A general assessment of the quality of the data can be found in:

- o Energy R&D Statistics in the European Research Area. Final Report (2005) Directorate-General for Research, Sustainable Energy Systems, EUR 21453. ISBN 92-894-8964-2

B.6.4 Market indicator (Number of filling stations worldwide)

The value chain of hydrogen energy technologies is complex and it varies according to the basic energy source. The current production of hydrogen is mostly based on the petrochemical industry. Almost 99% of present hydrogen production is used in the oil and chemical industry. The scope of this study is the as of hydrogen as a sustainable energy technology. This study has focused on hydrogen filling stations as best available indicator for the very early formative phase of hydrogen technologies.

The market indicator is defined as the accumulated number of hydrogen filling stations in operation in each country or region.

Primary sources is:

o http://www.netinform.net/h2/H2Stations/Default.aspx

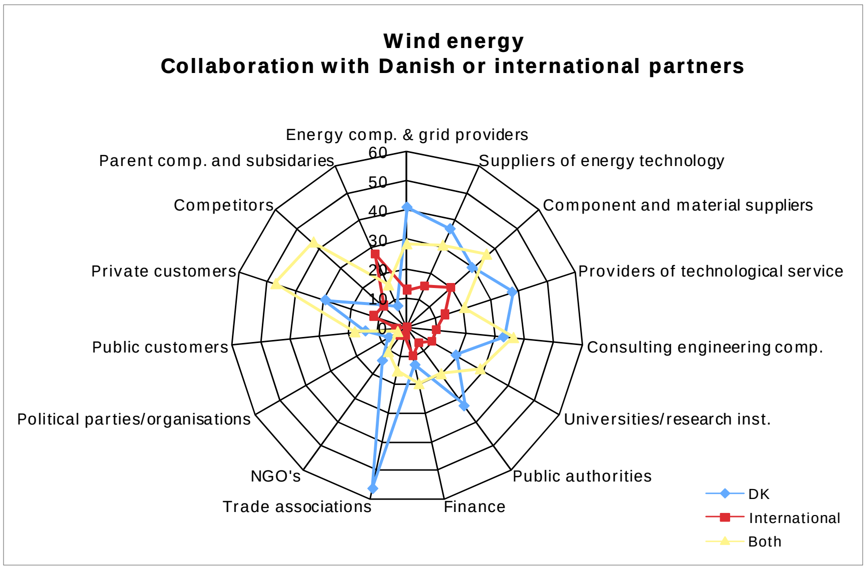
Data for this study is obtained by manually count of “green flags” in each country in this source.

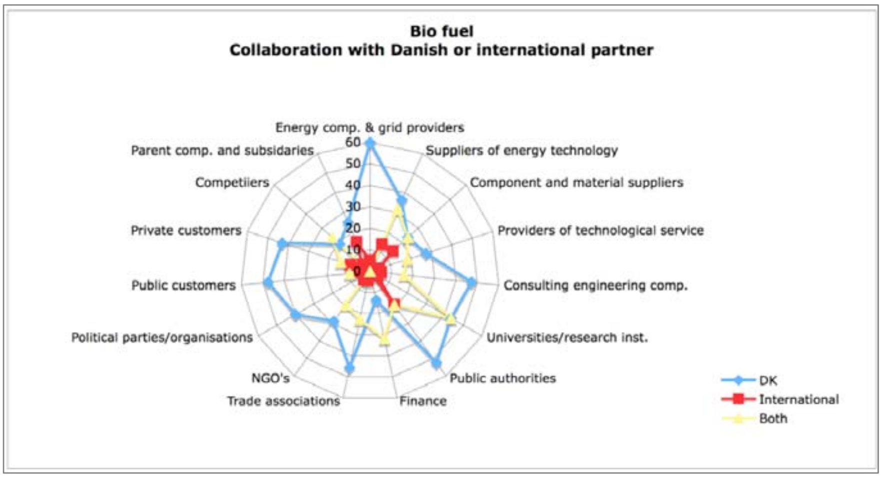
B.6.5 Industry indicator

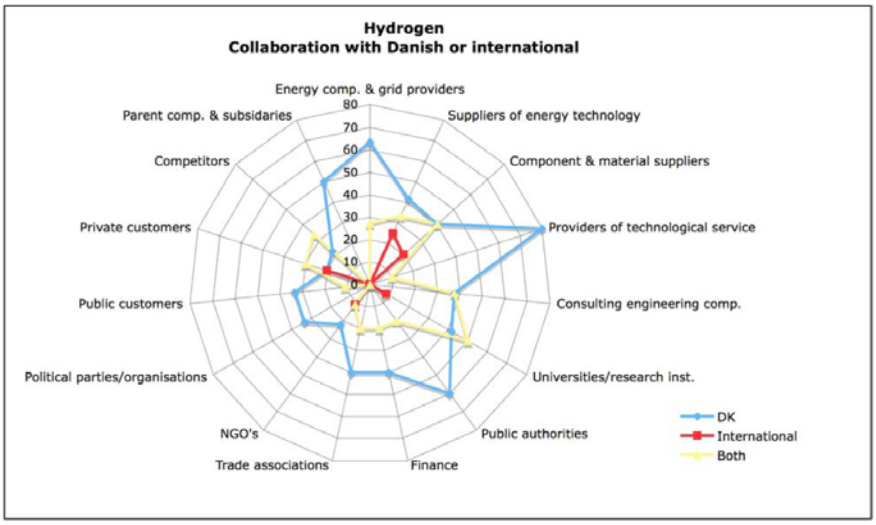
No globally comparable and reliable information is available Though for the interested quite a lot of information can be obtained from this online database on companies in the hydrogen industry http://www.fuelcellstoday.org/.

Appendix C

Domestic and international collaboration partners for actors in three technology areas in the Danish energy innovation system (biofuel here means bioenergy for heat & power). (Borup, Gregersen and Madsen 2007).







Public opinions in EU countries on selected energy technologies (source: EC 2007, Eurobarometer, Bruxelles: European Commission)