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A POLICY LEARNING PERSPECTIVE ON DEVELOPING SUSTAINABLE ENERGY TECHNOLOGIES[1]

The development of the Danish wind turbine industry is an illustrating example of the systemic nature of innovation processes and its dependency on co-evolution and interaction between technological, economic, political, and institutional elements. The paper argues that an innovation system approach and a related policy learning perspective can provide essential insights into the elements and relations influencing both the mutual success story of industry growth and energy policy based on wind power.

Keywords: Policy learning, innovation, Denmark, energy policy, wind power

1. INTRODUCTION

Since the late 1970s, wind power has played an increasing role in Danish energy production and consumption and during the same period the Danish wind industry has obtained a leading world market position. The development of this "new" sector is in many ways an illustrating example of the systemic nature of innovation processes and its dependency on co-evolution and interaction between technological, economic, political, and institutional elements. It is also a clear example on the importance of long-term regulation and determined government energy policy if the obtained industrial strongholds are to be maintained. When a liberal-conservative government in 2001 replaced a social-democratic one, it put renewable energy plans on standby with negative consequences for both the environment and the renewable energy sector. The home market for new wind power installations nearly disappeared, and other emerging growth sectors as, for instance, solar energy and bio-fuel simply lost momentum after 2001. Only recently have there been tendencies towards a return to a

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more renewable energy friendly policy. There are several factors and actors pushing for this change. One factor is the increasing broad awareness of climate change issues. Another is the question of energy supply security related to both potential political instability and the fear that the fossil fuels reserves will run out in the not so far future. Furthermore, various degree of lobbying from the renewable energy sector (not least from the Danish Wind Industry Association) has played an important role as well. Also the upcoming Climate Meeting in Copenhagen 2009 has clearly motivated the Danish Government to try to regain the reputation of Denmark as a renewable energy progressive country. Recently (November 2008), the Danish prime minister has signaled a change of policy towards less dependence on fossil fuels in energy production. We argue that an innovation system approach and a related policy learning perspective can provide essential insights into the elements and relations influencing both the mutual success story of industry growth and energy policy based on wind power and the less constructive story of missing opportunities when renewable energy policies are given less political attention.

The point of departure for analysis is a 'learning economy' concept where learning and knowledge are central aspects of the economic process. Section 2 shortly lists some key characteristics of a modern learning economy. Section 3 emphasizes the policy learning concept. Policymaking is described, not as a means-ends, rational choice activity, but as a process of policy learning including vision building, institutional learning, organizational learning, integration of different area-specific policies, etc. In section 4 the Danish Wind Power Innovation System is used as reference case to illustrate the mutual relations between industrial dynamics and policy learning. The focus is on the central factors and actors shaping the path of learning and innovation. The policy lessons learnt from the Danish wind industry 'adventure' are discussed in section 5 and section 6 summarizes the main conclusions.

2. THE LEARNING ECONOMY AS A POINT OF DEPARTURE

2.1. Learning and knowledge in the economy

The concept of the 'learning economy' is based upon the hypothesis that in the present phase of capitalist development an acceleration of both knowledge creation and knowledge destruction (learning and forgetting) has taken place. Individuals and organizations need to renew their competencies quicker and more often than before, because the problems they face change

more rapidly. At the same time the segments of society affected by accelerating change has grown considerably. Increasingly, the success of individuals and firms reflects their capacity to learn and to forget. Forgetting is often a prerequisite for learning and becomes necessary when old ways of doing things get in the way of learning new ways. To make a transition from fossil fuel based energy systems to energy systems based on renewable energies requires considerable scrapping of old routines and ways of thinking.

The acceleration of learning and forgetting is associated with the increasing speed of economic change in general, which creates a transformation pressure in many parts of society. The ability to learn and forget and to accept and absorb change thus becomes crucial for the competitiveness of individuals and firms as well as countries. For these reasons it is reasonable to refer to the learning economy as a new phase in economic development and not only a specific group of economies, which, for example, have developed their knowledge infrastructures and invested heavily in education and in R&D.

There is a difference between a knowledge based economy and a learning economy. Every economy is a knowledge economy but not every economy is a learning economy. The stone-age economy was knowledge-based. It is obvious that it required enormous amounts of mainly experience-based and tacit knowledge to survive in a harsh environment without the help of advanced tools and weapons. But it was not so much of a learning economy. New abilities developed slowly and old abilities took a long time to become superseded by new ones.

Knowledge may be regarded as a productive resource (a kind of “stock” or “capital”), while learning (and forgetting) is a process, which changes knowledge. In a way it is trivial to say that we live in a knowledge economy today since we have always done that. But it is less trivial to say that we live in a learning economy even if learning probably always has been a part of both human and social development.

Learning has even been described as a deeply ingrained human need. Veblen (1918) wrote about human beings as endowed by nature with both positive and negative instincts and propensities. There were negative propensities of predation and drives towards emulating the behavior of persons belonging to higher social strata. On the positive side there were the instincts of parental bent, workmanship and idle curiosity. Workmanship and, especially, idle curiosity compelled individuals to be industrious and creative and to strive for social and economic improvements. These instincts placed learning at the centre of technical and economic evolution.

Learning has always been important but in some periods the turnover of knowledge and social change in general are much higher than in other periods. This was, for example, the case during the heights of the industrial revolution. That the present phase of capitalist development qualifies as a learning economy does not imply that it is the first learning economy in history. It means, however, that we have to indulge in studies of its historical specificities as a learning economy if we want to understand the capitalist dynamics in the present period.

The dynamics of capitalism changes all the time and to understand what is going on, the notion of the learning economy seems more appropriate than the more common term 'the knowledge economy'. It focuses attention on the existence of different kinds of learning, which interact with each other and determine the dynamics of the economy. There is 'technical learning' leading to new production processes and products and there is 'organizational learning' introducing and reflecting new ways to organize firms. 'Institutional learning' develops new routines, norms, regulations, laws, etc. and leads to new patterns of behavior in society and 'policy learning' introduces and develops new types of policy making in regional and national government bodies. Capitalism, as a commodity producing system, also depends on 'consumer learning' which increases the aggregate demand through continued introduction of new or improved types of consumer goods and services combined with a willingness of consumers to establish new consumption habits.

There is an important distinction between, on the one hand, learning as a deliberately organized process, i.e. some parts of the economy, for example, universities, research institutes, and R&D departments, are organized with the creation and utilization of new knowledge in mind, and on the other hand, learning going on more or less as unintended by-products of normal economic activities such as procurement, production, and marketing. The learning economy is characterized by both these kinds of learning and, in addition, also by the attempts by many firms to build learning organizations, which deliberately combine indirect and direct learning (Jensen et al., 2007).

2.2. Conflicts and contradictions in the learning economy

The term "the learning economy" may seem to imply social harmony without serious conflicts. Who would oppose learning and increasing knowledge? But new knowledge often leads to the destruction of old knowledge and when new knowledge and competences are introduced into the economy, its structure is affected. The specialization pattern changes as

new or improved types of goods and services gain ground and older ones lose out. As a consequence the structure of employment and the distribution of income also change. And when firms reorganize to take advantage of new technical possibilities it has effects on the distribution of power and income.

These structural changes at the level of the firm as well as the economy as a whole create conflicts between different groups of people. In the learning economy firms are actively managing knowledge in many different ways. They buy, recruit, produce, recombine and adapt knowledge. The benefits and costs of these types of change are unevenly distributed in society and a faster process of structural change tends to increase social tensions.

These conflicts and tensions deeply affect the learning economy. Since learning is fundamentally and increasingly interactive, it requires a degree of social cohesion and trust to thrive. If conflicts about the distribution of income and power and about access to information and knowledge become too harsh, trust between people and growth will decrease, social cohesion will be reduced and learning will be hampered. Unregulated capitalism tends to polarize society and thus threatens the development of the learning economy. A strong state may use employment policies, education policies and social policies to reduce these conflicts, make them more manageable and support the build-up of the learning capabilities, which are crucial for success at all levels of the learning economy. Even if most high income countries use many resources to strengthen their education and research infrastructures, not all of them are actively supporting the learning capabilities of their citizens (especially different kinds of weak learners) through a broad range of policies designed to increase trust, communication and interaction in society.

In addition to this, knowledge in itself is characterized by several contradictions. Some of these are related to incomplete tendencies of commodification of knowledge. Even if firms want to have free access to new knowledge created in other parts of the private economy and in the public sector they also want to charge for the knowledge they create themselves. This feeds an accelerating process of commodification through the creation of intellectual property rights.

But some types of knowledge have inherent public goods characteristics and are difficult to transform into private goods. It may be expensive to produce new knowledge but once this is done the marginal costs of using it may be quite low. In fact, knowledge can be used over and over again without being diminished and sometimes it may even grow for example as a

result of learning by doing. Furthermore, it is difficult to sell knowledge – the buyer may not want to pay before he knows what he is buying and once he knows that he has no reason to pay.

In addition to this, from the point of view of society as a whole it may not be a good idea to privatize an inherently public good. Every time a public good is not used, because the requested payment is bigger than the marginal cost of supplying it, there is an unsolved efficiency problem, as anyone who has read an elementary textbook on welfare economics knows.

Usually we understand the existence of built-in conflicts and contradictions to be one of the characteristics of the capitalist mode of production and an important driver of capitalist development. From this point of view it is clear that the learning economy can be regarded as the latest phase of the development of capitalism and not just a modern variant of the "market economy". There are not many reasons to believe that the learning economy will be more harmonious and less riddled by conflicts than previous phases of capitalist development. This is also illustrated by the financial and economic crisis that hit large parts of the world economy in 2008. The crisis may to some extent be viewed as a result of a contradiction between on the one hand fast, short-term speculative movements of financial capital guided by advanced IT-systems and on the other hand the need for long-term planning of knowledge based competition in terms of new products and services.

As will be discussed in section 3 the contradictions of the learning economy also affect the process of policy learning and make the necessary coordination of different policy area more difficult.

3. POLICY LEARNING

3.1. Rational choice and learning in policy making

There are at least two ways of looking at economic policymaking. The most traditional way is to regard it as *rational decision making in a means-ends context*. This implies some rather strict requirements:

The policy maker must have *a well-defined goal function*. This may be either a social welfare function, which the policy maker tries to maximize on behalf of society, or it may be an expression of the policy maker's own, hidden agenda to maximize votes, income, power, etc. If there are more than one policy maker, for example, a central decision maker (the government) playing against a number of de-central decision makers (large firms, labor

market organizations, etc.) they must all have well-defined goal functions and they have to take into account that they are in a game situation.

The policy maker must also have *well-defined policy instruments and command over a competent bureaucracy with access to the necessary statistical data for the preparation and control of policy decisions.*

Given the existence of well-defined means and ends, there must exist *a model describing the structure, functioning and change of the economy.* The model has to be able to connect manipulations of the means/instruments with concrete descriptions of the resulting performance of the economy.

The policy-making also needs an adequate *institutional capability.* Appropriate laws, rules regulations as well as behavioral norms, routines and practices are necessary to avoid chaos and corruption and render credibility to the policy making process. This is often described as "good governance". This somewhat fuzzy concept usually includes 'the rule of law', 'political accountability', 'transparency in policymaking' and 'quality of bureaucracy' (Kaufmann and Kraay 2007). Without good governance it does not make much sense to describe policymaking as a kind of rational decision-making.

In addition to these institutional preconditions, rational policymaking also presupposes large amounts of different kinds of knowledge. *Know-what* in terms of access to and ability to use relevant statistical and other kinds of data and *know-who* (the knowledge about which person, organization or database to contact in order to get relevant data) are obviously important. The necessity of a model of the economy means that policy making also depends on *know-why*. Science-based knowledge about the structure, functioning and change of the economy as well as about the specific sector or activity policy makers are addressing is required. This know-why has to be combined with the *know-how* of a competent bureaucracy. Policymaking is not only a question of calculating the correct use of instruments from the model but also includes the use of much less formal knowledge about how to describe the situation, consult the involved decision-makers, prepare, implement and control the decisions, etc. It is a combination of the explicit and tacit parts of different kinds of knowledge. As the economy gets more and more complex the explicit as well as tacit knowledge requirements for "rational" policymaking become increasingly demanding. Furthermore, it seems safe to assume that the explicit as well as implicit value premises for policymaking also become more and more complex. Socially and ecologically sustainable development is a far more complex goal than economic growth, for example.

If one wants to regard policymaking as a rational choice in the sphere of politics one has, thus, to make quite demanding assumptions about values, knowledge and institutions. This may to some extent be justified in the case of a well-established type of economic policy, which has had many years to develop, like macroeconomic stabilization policy. Here we now have a rather simple goal function, a relatively firm theoretical understanding of the problems (though some economists might not agree on this point) and a well-developed institutional capability.

But this is far from the case for innovation policy or for energy policy and it is certainly not the case for a combination of these two kinds of policies. Neither the institutional capability in this area nor our present knowledge about industrial dynamics justifies a rational choice, decision-theoretical model of policymaking. In this situation it is more relevant to look upon policy making from an evolutionary perspective, as a process of *policy learning* (For an analysis of the development of a link between innovation theory and policy from the 1970s to the 1990s see Mytelka and Smith 2002.)

Policy learning is – together with technological, organizational and institutional learning – an integrated part of the learning economy. It implies that policymaking itself is a process of learning and that this process is more and more concerned with learning and competence building in many parts of the economy. The goals, the instruments, the models, the data, the competence of the bureaucracy and the supporting institutions develop over time in interaction with each other. This is to some extent done as a conscious process in which policy makers, bureaucrats, experts and scholars communicate and interact over time –*direct policy learning*. It is also done in a less conscious ”learning by doing” way, or even as “learning by accident” as when policy makers discover that environmental regulations also in some cases, unexpectedly, increase competitiveness – *indirect policy learning*.

3.2. Innovation policy learning

Policy learning can take different forms and in relation to innovation policy the following may be relevant:

- Forming visions about the learning economy as an environment for innovation and sustainable development and forming the value premises of innovation policy.
- Development of new concepts, data, and theories of innovation and systems of innovation.

- Institution building that supports the production and reproduction of human and social capital and diffusing international, regional and local 'good practices' in this field.
- Stimulating regional and local experiments in policy areas in need of reform and developing new methods to evaluate the outcomes of such experiments that take into account learning effects.
- Gradually trying, testing, evaluating and establishing new practices and routines in the conduct of policies stimulating learning and innovation
- Analyzing and comparing systemic features and critically important indicators in a form for benchmarking across regions, organizations and nations.
- Developing new forms of democratic participation in the design and implementation of innovation strategies including forms of ongoing dialogues between employees, unions, researchers and governments.

The concept of policy learning also implies a new perspective on a broad set of policies including social policy, labor market policy, education policy, industrial policy, energy policy, environmental policy, and science and technology policy. These policies may be looked upon both as specific areas of policy learning and as activities affecting learning and innovation capabilities in many parts of the economy. Furthermore, policy learning calls for co-ordination across these policy areas.

Social and distributional policies need to focus more strongly on the distribution and redistribution of learning capabilities. It is costly and difficult to redistribute welfare, ex post, in a society with an uneven distribution of competences and learning capabilities. Therefore there is a need for stronger emphasis on policies where weak learners (regions as well as individuals) are helped to increase their learning capabilities and competences.

The effectiveness of *labor market institutions and policy* has so far been judged mainly from a short run efficiency perspective. There is a need to shift to a focus on how the labor market supports competence building for individuals and firms. Some types of labor market flexibility and mobility are more productive than others and there may be alternative roads which are different from both the Anglo-American maximum individual flexibility and the Mediterranean contractual job security – for instance the Danish 'Flexicurity model', which is characterized by a specific combination of unemployment support, social security, labor market participation, unionization, and individual mobility.

Education and training policy needs to build institutions that at the same time promote general and specific competences, learning capabilities and life-long learning. This points toward educational and training methods that combine individual education programs with collective problem-oriented styles of learning. A commitment among employers, employees and policy makers to life-long learning with a strong interaction between schools and practice-based learning is necessary.

Industrial policy needs to include an adjustment to each other of competition policy and policies aiming at developing learning organizations and competence building networks. Intensified competition may stimulate superficial change rather than competence building if it is not combined with organizational change and new forms of inter-firm collaboration.

Energy and environment policies also need to take into account their impact on competence building and innovation in the economy.

Science and technology policy needs to support incremental innovation and the upgrading of competence in traditional industries as well as the formation and growth of high technology industries. For instance, employment of academically trained people in small and medium sized firms is a key also to the formation of networks with universities and other knowledge institutions.

All these area specific policies affect learning and competence building. They need to be designed with this in mind and be brought together into a common strategy. The globalizing learning economy calls for ongoing policy learning focusing on building competences and skills in all parts of society and on integrating narrow perspectives and strategies from different policy areas. This puts the co-ordination of policies and the long-term character of competence building into focus.

So far, policymaking in most countries has been heavily biased towards a rather narrow set of aspects of the learning economy. At the European level this bias can be seen for example in the empirical research and in the benchmarking exercises undertaken. The focus is on R&D expenditures, especially in science-based industries, patenting and tertiary education, while low- and medium-tech sectors, and learning by doing, using and interaction modes of learning and innovating are largely ignored (Jensen et al 2007). This clearly indicates that policy learning needs to be improved. The idea of rational policy makers is quite out of place.

The fact that many types of policy affects the learning capabilities of individuals and firms together with the contradictions in the learning economy, which were discussed in section 2, increases the need for policy

co-ordination. Learning capabilities have to be nurtured and defended. It is highly problematic, however, to leave policy co-ordination exclusively to Ministries of Finance and to Central Banks, which typically and traditionally is the case. Ministries of Finance have become the only agency taking on responsibility for coordinating many area-specific policies. Their visions of the world are necessarily biased towards the requirements of macroeconomic balance and thereby towards the short term, and they do not take onboard the fact that many area-specific policies affect learning and innovation in many parts of the economy. There is a need for policy learning in terms of building a new kind of institution for policy co-ordination. Such an institution would have as one of its strategic responsibilities to develop a common vision for how to cope with the challenges and contradictions of the globalizing learning economy. The basis of such a vision would be both a better understanding of the distinct national system of competence building and innovation and of the global context in which it has to operate.

Especially in a period of economic crisis it is important not to lose track of the long-term requirements of the learning economy. It takes considerable time to build up competences, but they can be destroyed quite quickly.

4. LEARNING AND INNOVATION WITHIN THE DANISH WIND POWER INNOVATION SYSTEM

It is clear that wind power policy in Denmark has never been conducted within a rational choice framework. The goals, the instruments, the relevant knowledge and the institutional framework have not been stable but have co-evolved and diversified since the industrial take-off in 1980s. It makes more sense to describe it as a process of both direct and indirect policy learning.

4.1. Systems of innovation as an analytical framework

Within the innovation system approach there is a distinction between systems that take a specific sector or a specific technology as a point of departure and systems, which build on some kind of geographical proximity – either local, regional, national, continental or even global systems of innovation. However, the concepts of technology-based and territorially based innovation systems are, depending on the analytical context, to be regarded as complements rather than substitutes. All systems of innovation are open systems and the different systems may overlap each other. A

specific firm, for example, may be a part of a sectoral, a local and a national system at the same time. Defining the Danish Wind Power Innovation System is an example of such a combination.

The main idea of the concept of innovation systems is that the overall innovation performance of an economy depends not only on how specific organizations like firms and research institutes perform, but also on how they interact with each other and with the government sector in knowledge production and distribution. Innovating firms operate within a common institutional set-up and they jointly depend on, contribute to and utilize a common knowledge infrastructure. It can be thought of as a system that creates and distributes knowledge, utilizes this knowledge by introducing it into the economy in the form of innovations, diffuses it and transforms it into something regarded as valuable, for example, international competitiveness and economic growth.

In the perspective of innovations as resulting from interactive learning we regard a national system of innovation as a system of actors (firms, organizations, government agencies, consumers, etc.) who interact with each other in ways that influence the innovation performance of a national economy. The innovation performance is influenced by specific parts of the institutional set-up, the knowledge infrastructure, the specialization pattern, public and private demand structure (or consumer tastes in the broad sense), and government policy.

This broad definition of a national system of innovation should not be interpreted as if innovation performance depends on almost everything. Only some aspects of, for example, the institutional set-up are really important for innovation performance and the trick is to identify these aspects. Likewise, only some of the connections between, for example, the production structure and the institutional set-up really matter. But this broad version of a national system of innovation provides a perspective – a way of looking at and understanding the determinants of innovation performance of a national economy. The concept of a national system of innovation in the broad sense opens up the very likely possibility that other types of policy than innovation policy, for example, education policy and energy policy, may affect innovation performance even more. It emphasizes the possibility that informal institutions in the form of norms of co-operation, habits of trust, collective and non-monetary incentives, etc., may influence innovations as much as formal institutions like patent rights and R&D-taxation. It provides new perspectives and enlightens new places to look for sources of innovation.

Infrastructures, production structures, institutional set-ups, consumer demand structures, and government policies are not independent explanatory factors for innovation performance. They are interdependent and they evolve in interaction with each other. For example, the development of a new industrial sector as the Danish wind turbine sector, is strongly affected by how fast and effectively an institutional supporting system is built up. Special financing institutions may be needed, standards may have to be created, R&D institutions and technological service systems may have to be developed, etc. The gradual strengthening of the new sector, in turn, leads to a firmer institutional support system and so on. The different subsystems could be thought of as co-evolving. The match or miss-match between for example institutions and specialization patterns is then an important aspect of the evolution of the system as a whole. In the same way there are important feedback mechanisms between the performance of a national system of innovation and its innovation determining factors. For example, a strong innovation performance in a specific sector may stimulate consumer learning and also lead to the strengthening of institutional and infrastructural support, which may lead to even better innovation performance, etc.

Our discussion of the groups of elements in national systems of innovation stresses that the boundaries of a national system of innovation are not completely defined in terms of national borders. It is an open system. It is also important to acknowledge that systems of innovation may be more or less coherent. They contain many subsystems knitted together into rather loose structures. They have evolved rather than designed and the cohesion of the systems changes over time and differs significantly between countries.

4.2. The Danish Wind Power Innovation System as an example of co-evolution of technological, economic, institutional and political factors

The Danish wind power story is well described in several sources (see for instance Dannemand Andersen (1993), Karnøe (1995), Jørgensen & Karnøe (1995), Krohn (1999), Hvelplund (2000), Kamp et al. (2004), Szarka (2006), Lipp (2007)). However, the story is still highly relevant as an illustration of a policy learning approach based on co-evolution of technological, economic, institutional and political factors. It also clearly illustrates that pro-active policy matters if a timely transition to renewable energy systems is to be implemented. Let free, privatization and market mechanism will not be able to secure such a transition and paradigm shift (Kemp & Rotmans 2005, Jacobsson & Lauber 2006, Smith 2008).

The production structure – from amateurs to world leaders

The strong anti-nuclear power movement and the energy supply crises in the late 1970s spurred a growing interest in alternative sustainable energy technologies in Denmark. Most wind power projects in the 1970s began as private projects, where technically interested people made experiments with scaled-down versions (10-15 kW) of the Gedser machine (Karnøe 1995, Krohn 1999). The use of wind power for electricity generation is more than 100 years old and goes back to the 1890s, where the Danish meteorologist, inventor, and folk high school principal, Poul la Cour, started experiments converting classical windmills to electricity generation. He gave courses in wind power for Danish "wind electricians" and after World War II during the 1950s one of his students, Johannes Juul, who worked as a chief engineer for a power company, took up his old passion for wind power and built a number of experimental machines. Juul was the first to connect a wind turbine with an (asynchronous) AC generator to the electrical grid. Around 1956 Juhl built the Gedser wind turbine that became a pioneering design for modern turbines. The 200 kW Gedser turbine remained the largest in the world for many years (Krohn 1999).

When the more "professional" turbine manufactures entered the scene in the late 1970s and beginning of the 1980s, they mainly came with a background in agricultural machinery (e.g. Vestas, Nordtank, Bonus, Nordex, and later Micon). One company, Wind World, was founded on gearbox and marine technology manufacturing (Krohn 2000). The wind turbine companies are in that sense an illustrating example of how learning is cumulative and often based in the national production structure and at the same time "accidental" or unplanned. While the Danish wind turbine manufactures, as mentioned, mainly had a background in agricultural machinery, the wind power companies in the US, Sweden, and Germany (e.g. Boeing, Lockheed, Westinghouse, MBB, and Siemens) had a strong background in aircraft and generator manufacturing.

In the late 1970s there were about 20 Danish manufactures entering the wind turbine market, but the home market was still modest. In the beginning of the 1980s the State of California began a program of support to wind power development and the Danish producers benefited and learned a lot from this expansion. However, when the California wind program ended in 1985-86, a large number of Danish manufactures went bankrupt or merged. The merger and acquisition process continued within the wind turbine manufactures, and today two companies, Vestas (merged with Micon) and

Siemens (acquisition of Bonus) are the dominating 'Danish' players. In many ways the wind turbine industry has followed a traditional industrial maturity path with increasing industrial concentration and capital intensity, growing internationalization of ownership and finance, and increased importance of R&D and patents.

The period from 1987 to 1991 was weak both regarding the domestic and the export market, but since the 1990s the development is characterized by a steady increase in especially the export market. In 2006 exports accounted for 99 per cent of sales, see figure 1. Export from the Danish wind industry was in 2006 27 billion DKK and the wind industry employed more than 21,000 people in Denmark. In 2006 Danish manufactures sold 5.439 MW power, roughly corresponding to 33 per cent of the global market. If turbine wings and other components are included, the Danish wind industry has a market share of 40 per cent of the global market (Danish Wind Industry Association, 2008).

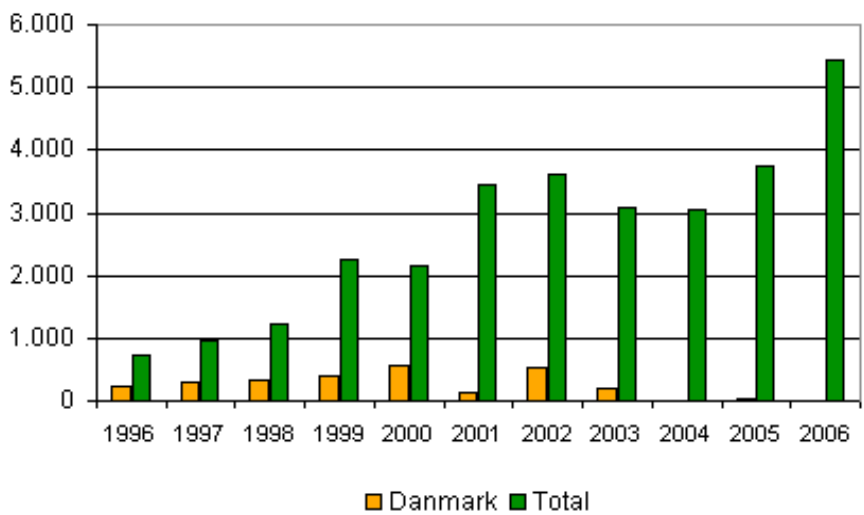

Figure 1: Wind turbine sales (Danish manufactures) in MW (1996-2006)

Source: Danish Wind Industry Association (2008)

The most important export markets for Danish manufactures in 2006 were the US, Germany, Canada and India (Danish Wind Industry Association, 2008), see figure 2. (Up-scaling has been a major characteristic

of the wind power production. The early machines produced 25 kW and had a 10.6m rotor diameter. Today's turbines produce 2-4 MW with 90 m rotor diameter placed on 100-150 m towers. More and more wind power capacity is produced in wind power parks and in the future more of these will be installed offshore.)

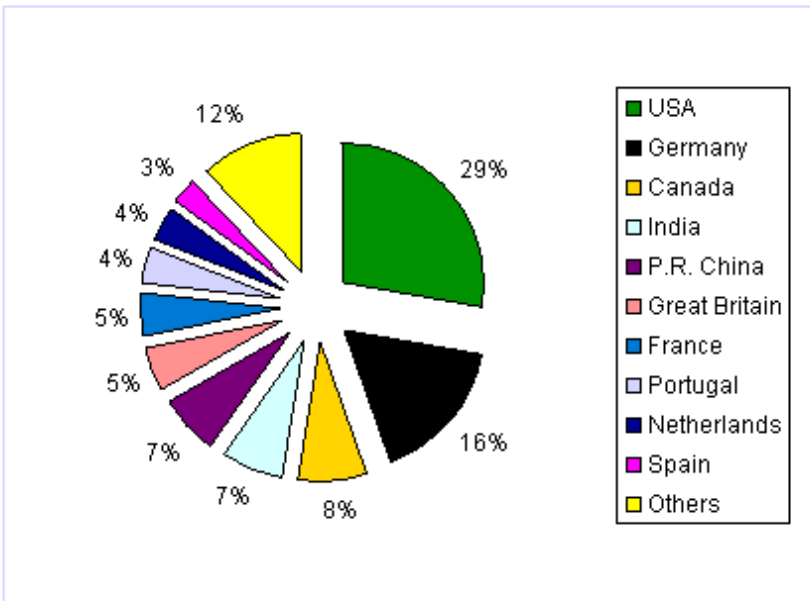

Figure 2: Danish manufactures markets (2006)
Source: Danish Wind Industry Association (2008)

In the first Danish energy plan from 1976 wind power was planned to cover 4 per cent of the total Danish electricity consumption. In the second energy plan (Energy Plan 81) the wind power share was expected to increase to 8 per cent in year 2000. Today (2008) about 20 per cent of Danish electricity production is covered by wind power. The latest Danish long term energy plan (Energy 2025) states that at least 30 per cent of electricity production in 2025 should be produced by renewable energy sources with the largest part coming from wind power (especially offshore). This is in fact a reduced ambition compared to the former energy plan (Energy 2001) aiming at 50 per cent of the energy consumption produced by a palette of different renewable energy sources in 2030. A more ambitious scenario developed by Megavind (a public-private partnership with key actors in the

wind power sector) has suggested 50 per cent of the energy consumption supplied by wind power alone. While the main arguments for increasing wind power electricity share in the 1970s and the early 1980s were a question of finding alternatives to nuclear power and securing the energy supply, the wind power strategy today gives a significant role to the required CO_2 reduction.

However, the dominating energy system is linked to the fossil fuels organizations and techniques with sectored divisions of heating, power and transmission. This dominating energy regime made it difficult for alternative technical systems like combined heat and power systems (CHP systems) and wind power to brake the barriers to entry (Hvelplund 2000). One important controversy between the power companies and private wind power producers concerned for instance the clearing price of electricity generated by the private wind power producers. The Danish government settled that dispute in 1984 by legislating that the power companies were obliged to buy wind power at a price equal to 85 per cent of the retail price of electricity.

A mixed palette of policy instruments has been introduced to stimulate Danish wind power production, and we only mention a few here. The utility obligation to buy wind power at 85 per cent of the retail price level was crucial. Another important measure was a 30 per cent subsidy of investments in new wind turbines. The investment subsidy was introduced in 1979, but was gradually reduced until it was abandoned ten years later. During this period, more than 3,000 cooperative wind turbines were installed. Typically, a cooperative wind turbine has between 20 and 40 owners. This means that by around 1990, there were between 100,000 and 150,000 owners of wind turbines in Denmark (Hvelplund 2000). Since 1985 the Danish government has ordered the utilities to install various amounts of wind power and recently, relatively high green taxes on all electricity – but with a partly refund for renewable energy including wind power – has made wind power much more attractive for the power companies.

The regulation regime (feed-in tariffs), where buyers of wind turbines receive a fixed price from the electricity companies and a fixed public service payment for CO_2-free electricity production from the Government, has motivated the producers to lower their production prices, as they were in a situation where more wind turbines could be sold if the prices decreased (Hvelplund 2000).

Knowledge infrastructure, knowledge sharing, and interactive learning

It is not possible (or intended) here to give a full description of the knowledge infrastructure that evolved in relation to the Danish Wind power Innovation System. Only a few key-players are mentioned below.

The establishment of the public wind power test station at Risø Research Laboratory in 1978 turned out to be crucial for the development of Danish wind power activities in relation to the production, distribution, and regulation of wind power knowledge. To receive the public investment grants, a wind turbine type approval from the national laboratory was required. This approval process was an important part of the knowledge development and diffusion both among and between the wind turbine manufactures and the investors, and thus stimulated an interactive learning process. The very strict safety and performance requirements put persistent pressure on manufactures to upgrade their design and manufacturing skills, and today Risø DTU is among the leading international research institutes on wind turbine technology and wind resource assessment (In 2007 Risø merged with the Technical University of Denmark, DTU.)

Most wind turbine owners are organized in the Danish Wind Turbine Owners' Association that publishes a monthly magazine with production figures and notes on technical issues. The statistical database, user groups, and technical consulting services for members have been important instruments to secure a transparent market based on shared knowledge (Krohn 2000). (See www.dkvind.dk for more information.)

The manufacturers of wind turbines have their own organization too – the Danish Wind Industry Association. The organization carries out an extensive information work, makes policy analyses, takes part in standardization activities, and is involved in national and international R&D-activities (See www.windpower.org for more information.)

In 2006 a new Public-Private Partnership, 'Megavind', was formed in order to formulate a coherent strategy for future innovation activities within wind power technologies. Members of the partnership network are key players within the wind industry, energy supply companies, universities, and the Danish Energy Agency.

It seems fair to conclude that knowledge sharing and interactive learning among key players have been (and still are) important characteristics of the Danish Wind Power Innovation System. At the beginning of the industrial development, an "open source strategy" seems to have prevailed for the benefit of the whole system, but it is an open question how today's

tendencies towards patenting and other forms of knowledge protection may influence knowledge sharing and innovation activities in the future.

5. LESSONS LEARNT FROM THE DANISH WIND POWER CASE

What are the main lessons that policy makers can learn from the Danish wind power case? And to what extent are these lessons relevant for stimulating other renewable energy technologies in the current Danish and international context?

Forming visions. The exclusion of nuclear power from the overall Danish energy system has paved the way for alternative energy strategies since the 1970s. The various national energy plans have been a key policy instrument to help form and implement a vision for a national energy supply system with a relatively high share of renewable energy – especially wind power. But this top-down policy would never have been implemented had it not been for the range of local private and public actors and 'advocacy coalitions' pushing and lobbying for increasing production and consumption of renewable energy. The policy process can best be characterized as a combination of bottom-up, top-down processes (Hvelplund 2000).

However, maintaining a long-term, pro-active policy with specific and ambitious targets for implementing renewable energy systems is essential. In that sense the sudden shift in Danish environmental and energy policy after the change of Government in 2001 had direct negative impacts on the development of renewable energy in Denmark. Wind power installations and other renewable energy investments were, as already mentioned, put on stand-by and the total public R&D spending in renewable energy experienced severe cuts (Borup et al. 2007). After nearly seven lean years for the Danish renewable energy sectors there is, however, hope for entering more progressive times again. Environmental concerns and the quest for sustainable development and long-term energy security have recently partly regained priority by the Government. Nevertheless, for the Danish solar energy and bio-fuels sectors the break in the domestic demand and political priority became costly – other countries (Germany, US and Japan) have meanwhile taken the lead leaving only smaller niche markets as options for new entrants.

Developing a system of innovation approach. Since most innovations occur as results of interactive learning processes in complex systems, system building, maintaining and coordination are necessary policy tasks.One of the

key factors for the success of the Danish wind power sector is the combination of energy and industrial policy right from the beginning. (A similar holistic view on energy, environment, innovation and industrial policy is seen in Germany in relation to the fast growing solar energy sector spurred by a subsidized home market.) In retrospect the policies may of course seem more coordinated than they actually were at the time, but the mutual interests and collaboration between domestic key actors within the innovation system have clearly paved the way for learning and capability building.

Establishing new practices and routines in the conduct of policies stimulating learning and innovation. The Danish wind power case shows that synergy can be obtained by a strategic combination of different instruments (market and non-market based). Following Midttun and Gausten (2007) different policy interventions are required (and are effective) in different stages of the product cycle. In the early innovative phase where risk and uncertainty are high, R&D policies and subsidies in the form of feed-in tariffs are relevant. Later niche market policies as for instance quotas (certificate market) may provide further stimulation for commercialization of renewable energy.

The various energy technology areas are quite diverse in a number of innovation-relevant issues like actor set-up, institutional structure, maturity, and connections between market and non-market aspects. The high degree of diversity between the different technology areas implies that an efficient innovation and energy policy has to take into account these differences. The policy has to be specific and reflect the variation in maturity. In areas like solar cells, where the market is formative, qualified demand – for instance in the form of strategic public procurement – is central for the technology to develop further. In areas like energy efficiency, where there are considerable markets within selected fields, indirect public policy support in the form of for instance information campaigns may be very effective (Borup et al. 2007).

Stimulating regional and local experiments. From an evolutionary point of view creating room for variety is crucial for the innovative dynamics. Quite an amount of experimenting with wind power has been supported during the period and different forms of financial and technical support for test-mills has been tried. An interesting case is the small Danish island of Samsø with 4,000 inhabitants. In 1997 the Danish Energy Agency initiated a national competition between the smaller Danish islands where the winner would be expected to convert all its energy consumption to renewable

energy within 10 years. Samsø won the competition and today the island is 100 per cent self-sufficient with wind-generated electricity. About 70 per cent of the heating needs of the island are met with renewable energy, and the transportation energy consumption is 100 per cent compensated by the electricity production from the offshore wind turbines. (For more information about this 'controlled experiment', see http://www.energiakademiet.dk).

Institution building. Institution building and institutional learning has all the way characterized the policy learning approach within the wind power case. The long-term energy plans, the establishing of the National Research Centre Risø and the various regulations and standards have been key formal institutions supporting learning and innovation. Of crucial importance for the knowledge generation and diffusion are the more informal institutions in the form of tight collaboration and extensive networking between the key actors in the Wind Power Innovation System, for instance the so-called Wind meetings, publication activities, industry associations, NGOs and various Public-Private Partnerships as the relatively new Megavind partnership. Such formal and informal institutions reduce uncertainty and shape the path of innovation.

Analyzing and comparing systemic features. Systematic monitoring and benchmarking of different performance indicators related to wind power production and consumption has been an integrated part of the technological, organizational, institutional and policy learning activities since the very beginning of wind power growth. At national level the Wind Industry Association and the Danish Wind Turbine Owners' Association have both played a key role in institutionalizing the data collection and providing and publishing systematic analyses of the results.

Stimulating democratic participation in the design and implementation of innovation strategies. In a way the whole area has been a testing ground for new forms of democratic participation in technical as well as policy development. Non-governmental organizations and publicly financed local energy offices as well as the traditional consumer-owned electricity system have played important roles in the process. Compared to most other countries there has been a broad public acceptance of wind turbine installations around the Danish country and coast sites. The broad social acceptance of many wind turbines in the landscape is clearly related to a participatory planning process combined with the economic incentives that government policy has provided for the many wind power owners. (Local participation and ownership is a key factor for the success of the Samsø

project mentioned above.) At the same time as there is a gradual, interactive process of policy learning in the Danish wind power system one can also identify a contradiction between its local and democratic aspects and the development of international electricity markets. The opening-up of the traditionally rather closed Danish systems threatens some of its interactive learning capabilities.

6. CONCLUSIONS

The policy lessons from the Danish wind power case of policy learning can be summed up in the following 7 points:

- Development of new energy technologies takes place in a context of high technological and market uncertainty. Such uncertainty can be reduced by a long-term combination of a visionary innovation and energy policy. Stop-and-go finance of, for instance, R&D projects, demonstrations projects and subsidies are often contra-productive.
- Continued innovation requires variety with room for experimentation and evaluation of alternative solutions to technological, organizational, institutional problems. Creating and utilizing such 'interactive learning spaces' (Arocena, Sutz 2000) is driven by a combination of innovative framework conditions at the system level and entrepreneurial 'fiery souls' at the individual level.
- New emerging energy technologies and energy systems as, for instance, solar energy and hydrogen require public support stimulating both the supply and demand side in order to be competitive with established fossil fuel technologies.
- Established technologies as, for instance, wind power needs continued stimulation through R&D and new domestic wind power installations if the domestic industry is going to stay competitive.
- The high degree of diversity between the different energy technology areas implies that an efficient innovation and energy policy has to take into account these differences. General policy initiatives like privatization and market liberalization will often be selective in practice by favoring existing technology systems.
- The public sector can play a special role for the development of new energy technologies via public procurement, investments, and creating various types of Public-Private Partnerships that stimulate democratic participation in the design and implementation of renewable energy strategies.

- The relative success of the case depends on the fact that it is a symbiotic combination of environmental, energy and industrial policies. The pure argument of supporting international competitiveness for an industrial sector would probably not have been enough to drive a continued process of institution building and policy learning.

The 7 points above are derived from specific Danish experiences, but at least in one important respect the lesson is quite general. Policies with complex targets, like increasing industrial competitiveness while respecting the requirements of sustainable development, necessarily involve different kinds of innovation. In such situations economic policy is not a question of rational decision-making, i.e., of finding the optimal mix of given instruments. It is rather a question of forming and sustaining a process of learning in which policy-making co-develops with technical, organizational and institutional change.

REFERENCES

Arocena, R., Sutz, J., *Interactive Learning Spaces and Development Policies in Latin America*, "DRUID Working Paper" 13/2000.

Borup, M., Gregersen, B., Madsen, A. N., (2007), *Development Dynamics and Conditions for New Energy Technology Seen in an Innovation System Perspective*, Paper presented at the DRUID Conference, June 2007.

Dalum, B., Johnson, B., Lundvall, B.-Å., *Public Policy in the Learning Society* in: Lundvall (ed.), *National Systems of Innovations – Towards a Theory of Innovation and Interactive Learning*. Pinter Publishers, 1992.

Dannemand Andersen, P., *En analyse af den teknologiske innovation i Dansk vindmølleindustri – herunder Prøvestationen for Vindmøllers dobbeltrolle som forskningsinstitution og godkendende myndighed [An analysis of technological innovation in the Danish wind turbine industry – including the dual role as research institution and as approval authority played by the Test Station for Wind Turbine at Risø National Laboratory] [in Danish*Samfundslitteratur, Copenhagen, 1993.

Edler, J., *Demand Oriented Innovation Policy*, Paper presented at the ProACT Conference, Tampere, Finland, March 15-17, 2006.

Edquist, C. (ed.), *Systems of Innovation, Technologies, Institutions and Organizations*. Pinter Publishers/Cassell Academic, 1997.

Edquist, C., Hommen, L., Johnson, B., Lemola, T., Malerba, F., Reiss and Smith, K., *The ISE Policy Statement*, 1998.

Foxon et al., *UK Innovation Systems for New and Renewable Energy Technologies: Drivers, Barriers and Systems Failures*, "Energy Policy" 33, pp. 2123-2137, 2005.

Gregersen, B., Johnson, B., *Towards a Policy Learning Perspective on the Danish Wind-power Innovation System*, Paper presented at the 3rd POSTI International Conference on "Policy Agendas for Sustainable Technical Innovation", 1-3 December 2000, London.

Gregersen, B., Johnson, B. (1998), *National Systems of Innovation as a Framework for Innovation Policy*, paper for International Conference on *Technology Policy and Less Developed Research and Development Systems in Europe*, Seville, 17-18 October 1997.

Hvelplund, F., *Danish Energy Policy at a Turning Point – Renewable Energy between Innovative Democracy and Oligopolistic "Liberalization"*, Institute for Development and Planning, Aalborg University, 2000.

Jacobsson, Staffan & Anna Bergek, *Transforming the Energy Sector, the Evolution of Technological Systems in Renewable Energy Technology*, in: *Industrial and Corporate Change*, Vol. 13, No. 5, pp.815-849, 2004.

Jacobsson, S., Lauber, V., *The Politics and Policy of Energy System Transformation – Explaining the German Diffusion of Renewable Energy Technology*, "Energy Policy" 34, pp. 256-276, 2006.

Jamison, A. (ed.), *Technology Policy Meets the Public, PESTO-Papers* 2, Aalborg University Press, 1998.

Jensen, M. B., Johnson, B., Lorenz, E., Lundvall, B.Å., *Forms of Knowledge and Modes of Innovation*, "Research Policy", Vol. 36 No. 5, 2007.

Johansen, L., *Lectures on Macroeconomic Planning, 1. General aspects*. North Holland, 1977.

Johnson, B., Lundvall, B.-Å., *Promoting Innovation Systems as a Response to the Globalising Learning Economy*, *Project Local Productive Clusters and Innovations Systems* in: *Brazil: New Industrial and Technological Policies*, 2000.

Jørgensen, U., Karnøe, P., *The Danish Wind-turbine Story: Technical Solutions to Political Visions?* In: Rip, A., Misa, T., Schot, J. (eds.), *Managing Technology in Society; the Approach of Constructive Technology Assessment*. Pinter, London, 1995.

Kamp, L. M. et al., *Notions on Learning Applied to Wind Turbine Development in the Netherlands and Denmark*, "Energy Policy", 32, 1625-1637, 2004.

Karnøe, P., *Dansk vindmølleindustri – en overraskende international success; om innovationer, industriudvikling og teknologipolitik [The Danish Wind Turbine Industry – an unexpected international success; about innovations, industrial development and technology policy][in Danish*. Samfundslitteratur, Copenhagen, 1991.

Kaufmann, D., Kraay, A., *Governance Indicators: Where Are We, Where Should We Be Going?*, "Policy Research Working Paper" 4370, The World Bank, 2007.

Kemp, R., Rotmans, J., *The Management of the Co-Evolution of Technical, Environmental and Social Systems* in: Weber, M. & Hemmelskamp, J. (eds.), *Towards Environmental Innovation Systems*. Springer, 2005.

Krohn, S., *Danish Wind Turbines: An Industrial Success Story*, Danish Wind Turbine Manufacturers Association, 1999.

Krohn, S., *The Wind Turbine Market in Denmark*, Danish Wind Turbine Manufacturers Association, 2000.

Lundvall, B.-Å., Borràs, S., *The Globalising Learning Economy: Implications for Innovation Policy*, Brussels, DG XII, 1999.

Lipp, J., *Lessons for Effective Renewable Electricity Policy from Denmark, Germany and the United Kingdom*, "Energy Policy" 35, 5481-5495, 2007.

Lundvall, B.Å., Borrás, S., *Science, Technology, and Innovation Policy*, in: Fagerberg, J., Mowery, D. C., Nelson, R. R. (eds.), *The Oxford Handbook of Innovation*. Oxford University Press, 2005.

Lundvall, B.-Å. , Johnson, B., *The Learning Economy*, "Journal of Industry Studies", Vol. I, No. 2, 1994.

Midttun, A., Gautesen, K., *Feed-in or Certificates, Competition or Complementarity? Combining a Static Efficiency and a Dynamic Innovation Perspective on the Greening of the Energy Industry*, "Energy Policy" 35, 1419-1422, 2007.

Mytelka, L. K., Smith, K., *Policy Learning and Innovation Theory: an Interactive and Co-evolving Process*, "Research Policy", Vol. 31, 1467-1479, 2002.

Remmen, A., *Greening of Industry – Technical and Institutional Change*, Aalborg University, 1999.

Smit, T. et al., *Technological Learning in Offshore Wind Energy: Different Roles of the Government*, "Energy Policy" 35, 6431-6444, 2007.

Smith, K., *The Challenge of Environmental Technology: Promoting Radical Innovation in Conditions of Lock-in*, Report to the Garnaut Commission: Final Draft, 2008.

Szarka, J., *Wind Power, Policy Learning and Paradigm Change*, "Energy Policy" 34, 3041-3048, 2006.

Veblen, T., (1918), *The Instinct of Workmanship, and the State of the Industrial Arts,* (Reprint 1964, Augustus M. Kelley, New York)

von Hippel, Eric 1988, *The Sources of Innovation*, New York: Oxford University Press.

Danish Wind Industry Association, www.windpower.org

Danish Wind Turbine Owners' Association, www.dkvind.dk

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