Learning to Grow: A Comparative Analysis of the Wind Turbine Industry in Denmark and India

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Introduction

The Emergence of Wind Energy

During the last few decades a number of governments have started to increase their focus on clean and renewable energy sources. Having committed themselves to substantially decrease their greenhouse gas emissions, governments have seen wind power as a promising technology with the potential of solving many of the environmental and energy problems facing especially the industrialized countries. The growth of wind energy has been fuelled by this increased awareness of both public and private parties in environmentally friendly energy technology.

In the late 1970s the increased awareness of environmental issues led to the strong anti nuclear power movement at the same time as an energy supply crisis led to greater focus being put on sustainable energy such as solar and wind energy. As a result of this changing attitude towards renewable energy, wind power has been the most rapidly growing renewable energy source over the last decade (Figure 1). Despite this high growth, wind energy development has been obstructed

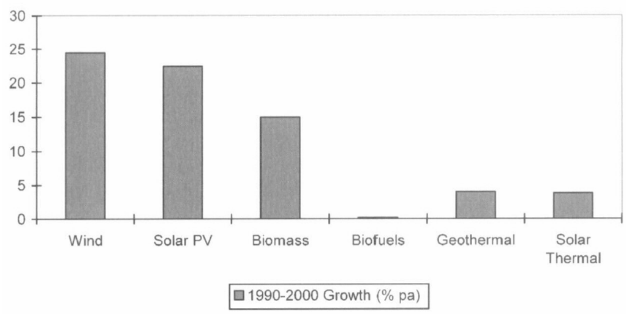

Figure 1: Growth of renewable energies. Source: Wong (2005)

with high investment cost, market failures and substantial opposition by established energy incumbents. Even though the cost of wind energy has fallen rapidly it is still higher than that of conventional energy (Figure 2). For these reasons substantial government involvement in the industry development has been seen as necessary. This has mainly been done through government supported R&D for the initial development and government subsidization and incubation strategies. However, implementing a successful technology policy[1] in an emerging industry is problematic because of the high degree of uncertainty. As has been pointed out by authors such as Maskell (1996) and Lundvall and Tomlinson (2000, 2002), the benchmarking or copying of already successful technology policies is not likely to reap substantial benefits. Even though the imitations of the policies are successful, the outcome will differ because the policies and institutions interact with firms and are rooted in distinct national and industrial settings. Given these difficulties, it is remarkable that India has in a relatively few years managed to position itself as one of the leading nations in wind energy.

[1] Technology policy refers to policies that focus on technologies and sectors. Technology policy often focuses on rapidly growing markets that are characterized by high rate of innovation (Lundvall and Borras, 2005).

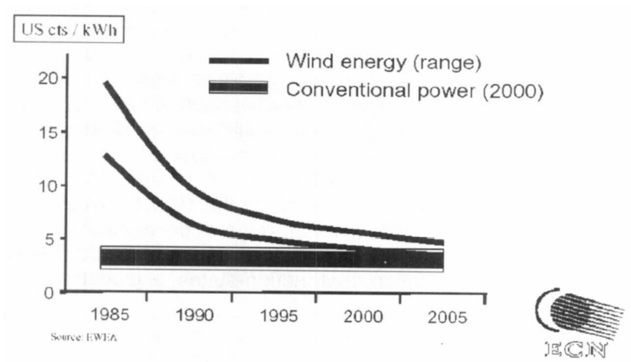

Figure 2: Generating cost of wind energy and conventional power. Source: Wong (2005)

Wind Energy in Denmark and India

In comparison to other countries, the history of the Danish wind turbine industry is a remarkable success story. Since the late 1970s Denmark has led the development of a global industry. In 2004 wind energy supplied 18,8% percent of Denmark's electricity consumption, equal to the consumption of 1.4 million Danish households. Today, Danish manufacturers have approximately 40% world market share and continue to be the world leaders in the wind turbine industry. The success story of the Danish wind industry has led many nations around the world to look towards Denmark when trying to develop their own wind turbine industry. However, matching the Danish success story is not a simple matter of applying the same technology policy tools in another national context. It is rather a complex problem of configuring the relevant actors, networks and institutions so that they complement the knowledge base and the technological trajectory of the industry.

In contrast to Denmark, India was a late comer to the global wind turbine industry. In 1985 the Indian government started an initiative to give impetus to wind energy generation. Despite going through more than one turbulent period during the development of the wind turbine industry, India is today the wind leader in Asia. A total of 875 MW of new capacity was commissioned during 2004 – the highest ever installation level achieved in a single year. India is also the fifth largest producer in the world (GWEC, 2005). Even so, given the vast potential for wind energy in India, there is still plenty of room for achieving even a bigger share in world markets. According to the Wind Energy Division of the National Aerospace Laboratories (NAL), nearly 40% of India's installed electricity capacity of over 120,000 MW could be generated from wind energy. Today India only gets 2.7% of its power from wind energy, using essentially imported machines[2].

The empirical objective of this paper is to analyse the evolution of the wind turbine industry in Denmark and India and to explain the relative success of India despite being both a developing nation and a late comer to the industry.

The paper is structured as follows. First we present the analytical framework we are using, that is sectoral system of innovation. Secondly, we look at how the knowledge base of the wind turbine industry has evolved from its origins in classic windmill technology to its current application in Denmark and India. Furthermore, we describe the development of the wind turbine industries in our case countries. In the next part we analyse the technology policy in the respective countries. Finally, we conclude by highlighting the importance of interactive learning for industrial development and the policy implications this entails.

[2] http://www.deccanherald.com/deccanherald/oct42005/snt.asp (as accessed on October 4th, 2005)

Analytical Framework - Sectoral Systems of Innovation

Studies in sectoral differences in innovation date at least to Schumpeter's *Theory of Economic Development* (1912/ 1934). From studies in R&D intensity to studies on technological regimes, a rich and heterogeneous literature of sectoral studies has clearly shown that innovation differs greatly across sectors, including in its characteristics, actors, sources and organization. One of the more recent additions to this stream of literature is the sectoral system of innovation The concept of sectoral system of innovation (further on referred to as SSI) gives a multidimensional and dynamic view of sectors (Malerba, 2005) and is influenced by evolutionary economics. Dynamics, process and transformation are at the centre of the analysis in the evolutionary theory, where learning and knowledge are key elements in the change of the economic system.

The other link of the sectoral system of innovation framework is with the innovation system literature, in which relationships and networks are key elements of the innovative and production processes (Edquist, 1997). The innovation system literature emphasizes learning as being a key element for development. One of the most cited contributions has been Arrow's analysis of 'learning by doing' (Arrow, 1962), where he demonstrates the efficiency of a production unit grew with the number of units already produced. He argued that this was a reflection of experienced based learning. Later, Rosenberg (1982) introduced 'learning by using' to explain why efficiency increases over time. In this paper we will however change from a linear to an interactive view on learning. The innovation process is then described as a process of 'interactive learning' (Lundvall, 1985, 1988) in which those involved increase their competence while engaging in the innovation process. This relationship can also be described as a mentor/apprentice relationship in which both parties benefit from increased interaction.

In SSI, we can find the coexistence of local, national and global boundaries, wherein, we find global boundaries for knowledge interactions; local boundaries for the labour markets and national boundaries for some key institutions. SSI have a lot of variability since they emerge and develop in continuously changing environments, are characterized by path-dependent processes and are embedded in different socio-economic contexts (Malerba, 2005). Malerba has further emphasised that SSI is a helpful tool for descriptive analyses of the innovation process in sectors; and also for recognising the factors affecting innovation. Similarly, it is useful for studies of the relationship between innovation and the changing boundaries of sectors and for a better understanding of the short-term and long-term dynamics and transformation of sectors; for the identification of the factors affecting the international performance of firms and countries in the different sectors and for the development of new public policy indications (ibid.). This approach highlights the importance of coevolution in innovative processes. And often coevolution is related to path – dependent process (David, 1985; Arthur, 1988). The local learning, interaction among the agents and network tends to generate increasing returns and irreversibilities that may lock sectoral systems into inferior technologies.

A sector is a set of activities that are unified by linkages to a specific product group and which share a common knowledge. When analysing SSI the focus is on three main dimensions of sectors; actors and their interaction, the institutions affecting the sector and the knowledge and technological domain. Over time the SSI undergoes a process of change through the coevolution of its various elements and therefore a dynamic and historical view of innovation is proposed. The sectoral innovation systems framework is especially useful tool for analysing emerging industries that in their essence are uncertain, innovative and highly dependent not only on the firms that populate the industry but as well on the relevant government organization, the technology policy and the institutions in the area.

As seen from the discussion above the firms do not innovate in isolation rather innovations are product of various complementary process. These complementary processes involve both firms as well as non – firm organisations (such as universities, research centres, government agencies, financial institutions and others). Thus the SSI approach emphasizes actors, networks, knowledge and institutions and the interactions between these elements. Thus a sectoral system could be seen as composed by three main building blocks: 1) knowledge and technology, 2) actors and networks, and 3) institutions. We will consider these 3 building blocks while undertaking our case study of the Danish and Indian wind industry.

Knowledge and Technological Evolution in the Wind Turbine Industry

Knowledge accumulation has played a central role in the growth of the wind turbine industry. Early developments were based on knowledge gained through the use of classic windmills as well as a high degree of experimentation. Today the wind turbine industry is a non-high tech growth industry mainly based on knowledge in mechanical and electrical engineering as well as some software and aerodynamics technology (Johnson and Jacobsson, 2001). In this section we analyse how the knowledge base of the wind turbine industry has evolved from the beginning of the last century to its modern development in Denmark and India. The evolution of wind turbine technology can be divided into two periods, the early period (1900-1970) and the modern period (1970-2005).

Even though we acknowledge that the technological and knowledge development of the wind turbine industry is a global phenomenon, the main focus here will be on developments within and between Denmark and India.

The Early Knowledge Base of the Wind Turbine Industry (1900-1970)

At the end of the 19th century electricity started to diffuse rapidly throughout the industrialized countries. In the early 1920s most large cities used electricity (Hau, 2000), while in rural areas the diffusion of electricity was slower, mainly because of high interconnection costs. Even though classic windmills were still being used in many rural areas to pump water their use for the generation of electricity was nearly unheard off.

The first modern wind turbine was developed in Denmark by Poul La Cour that experimented with classic windmill technology and electricity generation (Heymann, 1995). La Cour build one of the first direct current wind turbines which electrolysed water into hydrogen gas for illumination of a school in Denmark. By electrolysing water into hydrogen, Le Cour had solved the main storage problem with wind energy. In 1903, Le Cour founded the Association of Danish Wind Power Engineers which offered training courses for wind electricians (Hau, 2000:24). Le Cour also developed a new wind turbine he called the Lykkegard wind turbine, with a power output of approximately 30kW at 12 m/s wind speed. By 1908 seventy two of the Lykkegard turbine had been sold (Maltha, 2005) and Denmark was leading in rural electrification (Heymann, 1995:71).

Although the knowledge needed to build Lykkegard type wind turbines and others like it was at the time reasonably well stable and codified, the knowledge about aerodynamic flows around the blades was not as well developed[3]. Engineers realized that current theory in use was inadequate since it only took into account the front side of the blades, while the engineers knew from experience that

[3] The relevant scientific theory in use at the time was Newtons “mass-push-theory”. According to this theory only the frontal area of the blade where the wind hit the blade first was important (Heymann, 1995).

the rear side of the blades was important (Heymann, 1995). Slowly a new theory emerged in large part due to the efforts of three Danes: Hans Christian Vogt, Johan Irminger and Poul La Cour. This new theory was based on the pressure differences on both sides of the blades and lead to much more efficient designs. The Lykkegard wind turbines were build in sizes up to 20m in rotor diameter and power outputs ranging from 10-35kW and by 1920 around 120 were in operation in Denmark (Maltha, 2005). Despite the success of these turbines the interest in them faded after World War I, as relatively cheap oil and the connection of rural areas to the central electricity undermined the market for wind turbines. During World War II fuel prices soared again and for a short time the interest in wind turbines was renewed, however as soon as fuel prices dropped the interest in wind turbines for electricity generation also fell.

This period, from the start of the 20th century until the end of the Second World War was the first era in which wind turbine technology emerged. The knowledge base was drawn from classic windmill technology and the designs were based on experience and experimentation. These designs suffered from lack of understanding of aerodynamic principles and were limited to general and affordable materials.

Modern Developments in Wind Energy Technology (1970-2005)

Due to the connection of most rural areas to central electricity and the availability of cheap oil, the interest in wind energy had grown weak after the Second World War. However, voices promoting the use of wind energy to provide a large scale supply of cheap electricity never quite died down. In the early phases of the industry development most wind energy projects began as private projects. These experiments in the 1970s were mostly done by technically interested people who used a scaled down version (10-15kW) of the Gedser machine (Krohn, 1999)[4]. Later, during the late 1970s and the beginning of the 1980s, serious turbine manufacturers entered the scene. These manufacturers mainly came with a background in agricultural machinery.

In the 1970s the world faced an energy crisis and as a result many politicians were inspired by the enormous dependence of the industrialized nations on scarce fuel resources. As a result large government supported projects were started in among other nations the US, Denmark and in Germany. The objective of these demonstration projects was to develop cost-effective wind turbines.

The Danish government started with two R&D projects: the Nibe A and Nibe B. Both turbines were 3-bladed 630kW upwind designs based on the so called Gedser turbine and about 3 million US was invested in each project. However, some problems in the design lay with the blend of glass fibre and steel rotor blades, which were expensive and tended to damage. In 1984, the turbines were fitted with new wooden rotor blades that withstood the stress well. However an economically viable operation of these turbines was not possible. In 1985, the Danish government started a second large wind turbine project. For this wind park an enlarged version of the Nibe B wind turbine was used, with rotor blades completely made out of fiber glass. The experience gained from the Danish wind energy program provided some useful results but engineers had to acknowledge that large and reliable wind turbines were more difficult to realize than expected.

The Government of India initially gave incentives to grid quality power generation by wind turbine technology in 1985. However, India's knowledge base in wind energy generation was weak and

[4] Around 1956 Johannes Juhl, a former student of Poul La Cour, built the Gedser wind turbine which became a pioneering design for modern turbines.

needed significant growth to be competitive at an international level. As a result the Indian government embarked on a series of cooperation projects with leading actors to develop the knowledge needed. This policy was made easier by India's unique position as a market with a huge potential for the wind turbine industry as well as its status as a developing country.

The Evolution of the Danish and Indian Wind Turbine Industries

In the late 1970s about 20 Danish manufacturers were in the wind turbine market. While the home market was still not big the Danish manufacturers learned a lot from the exports to the US. The exports to the US emerged as the State of California, in the beginning of the 1980s, began a program to support wind energy development. However, when the program ended in 1985-86 many Danish companies went bankrupt or merged (Krohn, 2000). As a result the period from 1987 to 1991 was difficult one for the Danish wind turbine industry but since 1992 the development of the wind turbine industry has been characterized by a steady growth (Figure 3).

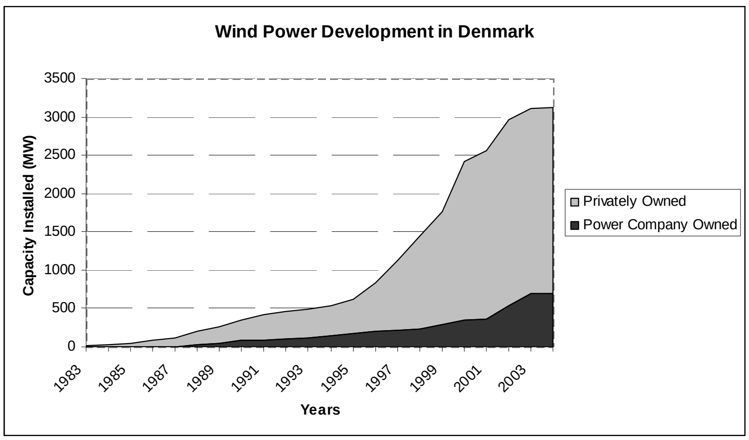

Figure 3: Wind Power Development in Denmark. (Source: Danish Wind Industry Association)

Today the wind turbine industry in Denmark consists of approximately 110 firms. That includes 3 big producers, Vestas Wind Systems A/S, Siemens Wind Power A/S and LM Glasfiber A/S plus a number of suppliers and sub-suppliers. Most of these companies interact not only through business interactions but also through the Danish Wind Industry Association (DWIA) that was founded in 1981. Today DWIA represents 99.9 per cent of Danish wind turbine manufacturing measured in MW and more than 112 companies with activities in the Danish wind industry. DWIA has played a central role in the evolution of the industry through publication of material related to the industry as well as providing a single voice to the businesses within the industry. This strong network of firms was essential in the emerging phases of the industry when government decisions often played the central role between life and death. The modern Danish wind turbine industry was created around its home market that provided it with the necessary testing ground to develop the capabilities needed both in manufacturing processes as well as in wind technology (Krohn, 1998). The experience gained in its home market has helped the Danish firms to establish themselves in India.

India saw, in the mid - 1980s, the removal of industrial licensing policies and the liberalisation of policies concerning entry of foreign companies, whereas, in the early 1990s, the trade policy reforms were undertaken (Patibandla, 2002). Thus mid - 1980s not only marks the transistion period from the energy sector reforms in India, it also marks the new development in the overall policy making in the country. Designing organisational structure was not a major concern for Indian firms in the pre-reforms period since they had access to a highly protected and non-contested home market. In the pre - reforms period, with regards to technology, most Indian firms were observed to have made minimal investment in R&D assets (Lall, 1987). It was a general practise to import older vintage technologies and minimal efforts were made in adapting them and building technological dynamism. Hence, most Indian firms were far below their international technology frontiers. When faced with competition in the post - reforms period, local firms in India appear to be able to replace technological assets with less difficulty than organisational assets. Local firms adopted more efficient technologies through imports and increased expenditure on R&D (ibid.)[5]. The policy reforms in the 1990s allowed foreign firms to increase their equity share above 40 per cent and in some sectors there are even 100 per cent-owned multinational subsidiaries. One of the results of this policy has been the substantial presence of Danish firms in the Indian wind turbine industry.

As seen from the Figure 4, the initial wind turbine production in India was mainly demonstrative in nature, where the government was the major instrument. Thus, one of the major actors in the development of the wind energy sector in India has been the Government and its wind energy friendly policies. Today the biggest Indian state in wind energy is by far Tamil Nadu[6], in the south of India.

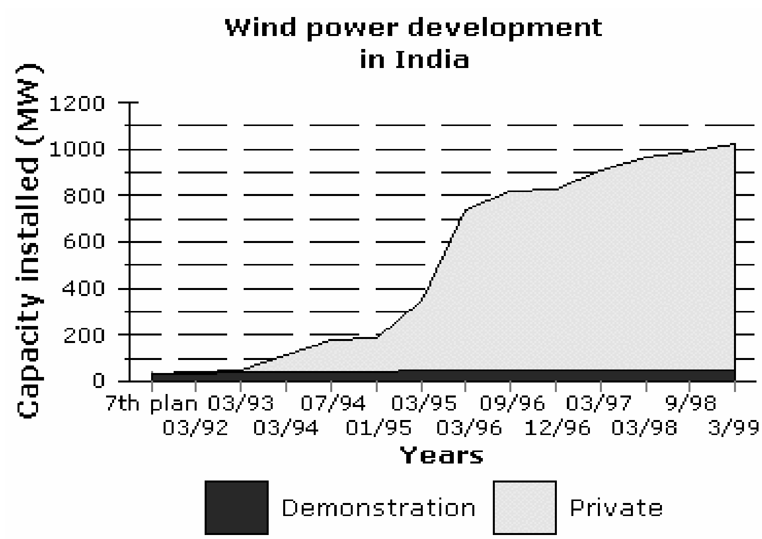

Figure 4: Wind power development in India (Source: TERI Project Report No. 2000RT45)

The Centre for Wind Energy Technology (C-WET) based in Tamil Nadu and established in cooperation with the Danish government, has acted as a technical focal point for wind power development in India. In Tamil Nadu the first wind farm with 10 of the 55 kW of wind electricity generators (WEGs) was installed in 1986. Ever since then Tamil Nadu has made rapid progress with major funding assistance from MNES and with the local cost shared by Tamil Nadu Energy Development Agency (TEDA) and Tamil Nadu Electricity Board (TNEB) equally. It has so far established demonstration wind farms at eight areas with a total capacity of 19.10 MW. As on 31-12-2001 these demonstration wind farms in Tamil Nadu with 117 wind electric generators have cumulatively generated and fed into electricity board grid a total of 312.5 million units of electricity. The Tamil Nadu Energy Development Agency (TEDA), nodal agency of the Ministry of

[5] Import of capital goods and intermediate products were allowed more liberally than finished goods since the mid-1980s in India.
[6] Tamil Nadu numbers from the Indian wind energy association webpage

Non-conventional Energy Sources (MNES) is a Tamil Nadu government undertaking to promote renewable sources of energy and energy conservation activities. It has been a major catalyst of the tremendous growth Tamil Nadu has made in the development of wind power. TEDA has undertaken state-wide wind resource assessment programme right from 1986 with the funding assistance of Government of India (MNES) and Government of Tamil Nadu and with the Technical Assistance of Indian Institute of Tropical Meteorology, Bangalore. Installed at 67 wind prone zones each covering 10 sq. km area, 39 zones were considered as viable for commercial exploitation and out of these 17 zones have been exploited. Also the programme of installation of windmills for water pumping is being carried out in Tamil Nadu on subsidy basis with the funding assistance of MNES & Government of Tamil Nadu. Motivated by the success of the above government programmes, private sector has made rapid strides on wind power generation. The first private sector wind farm of the country was set up in Tamil Nadu during 1990 with two wind electricity generators of 250 kw each at Muppandal.

The National Aerospace Laboratories has been involved in the development of wind turbine development programmes which being largely funded by the New Millennium Indian Technology Leadership Initiative (NMITLI) of the Council of Scientific and Industrial Research (CSIR), the Centre for Wind Energy Technology (C-WET), Chennai and the Sangeeth Group of Companies, Coimbatore as the industrial partner. Indian wind speeds, for instance, are much lower than European wind speeds, and it is known that the wind power generated is proportional to the cube of the wind speed. Lower speeds, therefore, drastically affect the wind power output. Unless a turbine is properly rated to efficiently generate electricity at these lower speeds, it is not going to work well in India. And hence, NAL is involved in building wind turbine that are adapted to the Indian conditions[7].

To summarize[8], the demonstration projects, which began in 1985, were being implemented through the State Governments, State Nodal Agencies or State Electricity Boards. They, together with extremely favourable financial incentives, have created the conditions that have allowed the wind energy market to expand from just 32 MW of installed capacity in early-1990. The Indian Renewable Energy Development Agency (IREDA) has played a significant role in the promotion of wind energy, attracting bilateral and multilateral financial assistance from world institutions and the private sector. There are but few indegenous private players in this sector which are actively pursing the process of innovation and adapation of the foreign technology to meet the local needs and seek international accreditation.

Initially, financing institutions other than IREDA were not willing to invest in wind power projects due to lack of exposure and experience in this sector. In 1993-94, the World Bank provided financial assistance of $43 million for wind energy to IREDA. This opened the window for large-scale financing and catalyzed the growth of the industry in the mid-1990s. The growing interest among wind project sponsors encouraged other financial institutions (FIs) to begin financing wind projects. These included the Industrial Development Bank of India (IDBI), the Industrial Credit Investment Corporation of India (ICICI), the Gujarat Industrial Investment Corporation Limited (GIIC), the Power Finance Corporation (PFC), the Industrial Finance Corporation of India (IFCI) and the Rural Electrification Corporation (REC) (Mishra, 2000).

[7] http://www.deccanherald.com/deccanherald/oct42005/snt.asp (as accessed on october 4th, 2005)
[8] Among others, http://www.worldenergy.org/wec-geis/publications/reports/ser/wind/wind.asp, http://www.cwet.tn.nic.in/Research.htm, http://www.cwet.tn.nic.in/Standards.htm

The Role of the Utilities
One of the main problems for many countries in developing their wind turbine industry has been the role of energy utilities. Energy utilities have had a substantial effect on the way the wind turbine industry develops through their "stewardship" of the energy grid but are usually not big investors in wind energy technology. Their involvement can therefore both hinder and facilitate the development of a successful wind turbine industry.

The Danish electricity system, consisting of power plants, transmission and distribution systems, is consumer owned through co-operatives or indirectly via municipal ownership. These utilities are mostly non-profit organizations with profits being back to consumers through lowering of electricity prices. This system has been very cost efficient and Danish electricity prices are among the lowest in the EU (Gregersen and Johnson, 2000). The downside of this system for wind energy is the systems linkages to the fossil fuels organisations with sectored divisions of heating, power and transmission. This has made it difficult to for wind power companies to enter the market (Hvelplund, 2000). The clearing price of electricity coming from wind power producers has been an one of the hardest controversies to overcome for the cooperation between the power companies and the private wind power producers. In 1984 the Danish government settled the dispute by legislating that the power companies are obliged to buy wind power at a price that is equal to 85% of the retail price of electricity. Even though the power companies have increased their investment in wind power, this only amounts to about 15% of the Danish wind power production. The other 85% is still owned by wind energy co-operatives or individual farmers (Gregersen and Johnson, 2000).

In India there is a considerable resistance among the State-run utilities to grant "third party sale"[9] facility to wind power producers (Rajsekhar et al, 1999). The utilities see this as competition for their most high end industrial customers. Complicating the situation is the presence of the State-run utilities as the primary customer of wind energy producers. However, the utilities see the wind energy producers as a peripheral supply option and possibly as a nuisance because of their low reliability (ibid.).

University Relations
In Denmark, not only the private firms but also the universities have been in the forefront of technological frontier in development of wind turbines. For example the Sustainable Energy Planning Research Group at Aalborg University.[10] The Sustainable Energy Planning Group is working interdisciplinary with Sustainable Energy Planning and Management groups and is responsible for the Masters' programme in Sustainable Energy Planning & Management (SEP&M), which is a two years' international English language master's programme. Since the early 1970s this group at Aalborg University has been part of Danish energy planning process. Both at national levels as well as local levels, the group has developed strategies for energy conservation and development of renewable energy sources. Specific proposals for institutional conditions for wind turbines and small CHP plants etc. have been analysed and designed on both national and local levels. The researchers have regularly been involved in the design of Danish energy policy and implementation at both local and national levels. In the initial stages of the wind power development, around 1975, the wind power was expensive than its fossil fuel competitors. But Aalborg University and others saw the technological potentials and a policy was implemented

[9] Third party sale facility amounts to allowing wind power producers to use the grid infrastructure to sell power to any industrial client at any mutually agreed rate.
[10] http://www.plan.aau.dk/tms/energy/indexuk.php?id=4&st=1

which supported the technological development in the relatively costly initial stages of wind power development. And today wind power is one of the most successful export industries in Denmark. Similar wind energy focused program also exists in Department of Mechanical Engineering at Technical University of Denmark. In the Fluid Mechanics Section, a group of 4 researchers have worked with wind energy research during 20 years. The primary funding has been through EU projects and through projects funded by the Danish Energy Agency.[11]

Another example is Risø which is a national laboratory under the Ministry of Science, Technology and Innovation.[12] Risø carries out research in science and technology and provides Danish society new opportunities for technological development. Risø collaborates with universities, research institutes, technological institutes and the industrial sector on a national, European as well as on an international basis. The Wind Energy Department of Risø has steadily grown and as of now employs a permanent staff of 100 persons, of which 2/3 are scientists and engineers. The department is organised in research programmes with attached commercial and technical services. Risø also has PhD and post-doctorate programmes. Some of the Risø objectives include global application of wind energy, to advance the basic atmospheric physics which is used to calculate the effect of the wind on major constructions and buildings and to develop new opportunities and technology for the exploitation of wind energy.

In India, there exists a high degree of interaction between the government agencies and the universities in wind turbine technology. One of the more successful ones has been the case of TEDA and Indian Institute of Tropical Meteorology, Bangalore. TEDA has undertaken state-wide wind resource assessment programme right from 1986 with the funding assistance of MNES and Government of Tamil Nadu and with the Technical Assistance of Indian Institute of Tropical Meteorology, Bangalore. Additionally, educational institutes were set up as a fruitful outcome of the interaction between India and Denmark. In 1994 two Environmental Training Institutes (ETIs) were established under the Danish cooperation programme in the Karnataka and Tamil Nadu states of India. The purpose of the programme has been to equip the ETIs with training facilities and to develop local trainers who in turn provide training to regulatory authorities, municipalities or companies. The ETIs have developed 24 training courses on several environmental themes and have trained more than 5000 participants. ETI Karnataka has acquired ISO 9000 certification. ETI Tamil Nadu is also planning to do so. As mentioned before, these kinds of cooperation have lead to India being one of the leading nations in certification and quality assurance in the wind turbine industry.

Interactive Technology Policy Learning in Denmark and India

Broadly speaking there are two views on technology policy. The first view, which can be termed "pro-market view" claims that profit maximizing firms driven by competitive pressure, will develop technologies that are both profitable and beneficial to society. The proponents of this view argue for a market based technology policy with the possible exception of subsidization of R&D. Technological change is seen as exogenous to the system. Therefore, this view of technological change is really not a view on technological development and innovation but about the efficient utilization of technologies, given the state of technological knowledge. The alternate view is the "state promotion" view that identifies the many market imperfections that slow down the pace of technological innovation. The proponents of this view argue that policy interventions are needed to

[11] http://www.afm.dtu.dk/Windenergy/index.html
[12] http://www.risoe.dk/risoe2.htm

create incentives for growth and innovation, since the process of technological adaptation is subject to a number of important market imperfections.

The wind turbine industries technology policy has been characterized by the state promotion view, as generation costs of wind energy has historically been considerably higher then that of conventional energy sources. Internationally, the role of the state has therefore been prominent in getting the industry through its emerging faces. The role of technology policy has likewise been a very important one and in many cases has been a crucial factor in determining an industries survival or demise.

Danish Wind Energy Policies

In Denmark a mixed box of policy instruments have been used to stimulate Danish wind power production, both demand pull and technology push instruments. The utility obligation to buy wind power at 85% of the retail price, legislated by the Danish government in 1984, has been crucial. Another important factor has been the introduction of a 30% investment subsidy of investments in new wind turbines. This investment subsidy was introduced in 1979 and was then gradually reduced until it was abandoned in 1989. Since 1985 the Danish government has ordered the utilities to install various amounts of wind power, from 100 MW on 1985 to 750 MW offshore wind power in 1998 (Gregersen and Johnson, 2000). Additionally, relatively high green taxes on all electricity with a partly refund for wind power has made wind power more attractive option. In a Danish energy plan from 1976 wind energy was planed to cover 4% of Danish electric consumption. In the following energy plan13 this share was planned to be 8% by 2000. Today, this share is 18,8%. The most recent Danish energy plan states that in 2030 renewable energy sources should provide 50% of the energy consumption. The largest part of this is planned to come from wind energy (Gregersen and Johnson, 2000).

Denmark was the first country to promote aggressive quality certification and standardization in wind turbine technology (Lewis and Wiser, 2005). As early as 1979 the Riso National Laboratory began approving turbine design to ensure reliability and safety standards were met (Sawin, 2001). This procedure was instituted with the support of owners, manufacturers and the Danish authorities who all had an interest in ensuring the quality of Danish wind turbines.

Indian Wind Energy Policies

The Government of India initially gave incentives to grid quality power generation by wind turbine technology in the 7th National Five Year Plan (NFYP), which ran from 1985 to 1990. By the start of the 8th NFYP, wind power generation became the thrust of India's Ministry of Non-conventional Energy Services (MNES). MNES has formulated a series of policy incentives and fiscal incentives that have been successful in the development of the wind power sector. On top of this policy, individual state governments have declared their own incentives. These incentives have created an attractive investment environment that has led to a surge of investment in the sector. The fiscal incentives extended by the Indian government to the wind turbine sector are of twofold. Direct taxes – 80 per cent depreciation in the first year of installation of a project and a tax holiday for 10 years.

One result of these incentives has been to encourage industrial companies and businesses to invest in Indian wind power. An important attraction is that owning a wind turbine assures them of a

[13] Energy Plan 81

power supply to their factory or business in a country where power cuts are common. Wind farms in India therefore often consist of clusters of individually owned generators. Much of the installed capacity is in the states of Tamil Nadu (61 per cent), Gujarat (14 per cent), Maharahtra (12 per cent), and Andhra Pradesh (7 per cent). The private sector has dominated investment (97 per cent) in these regions (GWEC, 2005).

Interactive Learning between India and Denmark

In 1987 the Government of Denmark and the Government of India established a cooperation programme that conceived a 20 MW wind energy demonstration project. The project included a 10 MW wind farm in Gujarat and two wind farms (4 MW and 6 MW) in Tamil Nadu. In 1990 the wind farms were successfully commissioned. The success of this project led to cooperation between Danish and Indian companies by establishing production facilities for wind turbine generators in India. As a result of this development the need for strengthening the associated technological infrastructure with respect to the quality and standards of wind turbines became clear. In 1997 the Government of India and the Government of Denmark agreed to establish a national wind turbine test station under Centre of Wind Energy Technology (C-WET). The aim of this project is to build and strengthen the Indian capacity for testing, certification and quality assurance aspects of wind turbines. As a result of this policy India is now considered one of the three world leaders in this area of the wind turbine industry[14].

In India, Danish designed windmills have played an important part in the learning and knowledge generation within the industry. Since the early 1970s eight main generations of Danish wind turbines can be distinguished (Nejl et al. 2003). The first generation wind turbines were based on 5 meter long rotor blades. This made it possible to build wind turbines with an output of approximately 15 to 30kW. This first generation was primarily sold between 1971 and 1981. The second generation of wind turbines had 7,5 meter long blades and an output of 55 to 75kW. The sales of these turbines peaked in 1985 but were first sold in 1980[15].

The current version is the eight generation which was a radical leap forward, with turbines up to 2500kW and rotor blades between 36 and 40 meters long. The ninth generation is already in testing, as many manufacturers have developed wind turbines with capacity of up to 5MW and with rotor diameters of 100 meters or more (Neilj et al. 2003: 38-42).

In 1986 wind farm activity started with a boom in India. Five wind farms at Mandvi, Okha, Devgarh, Puri and Tuticorn were installed. These wind farms used mostly the second generation of wind turbines. In 1988, in the second phase of the program, wind turbines from the third generation were introduced (Singh, 1998). These and other wind farm developments in India have substantially benefited from the high degree of Danish involvement and expertise. These benefits have come both through the use of Danish wind technology and through knowledge transfers in

[14] The others being Denmark and Germany

[15] The third generation allowed for turbines sizes of up to 100kW with around 9 meter long rotor blades. The fourth generation turbines used approximately 12 meter rotor blades with a turbine size of 150 and 250kW. The fifth generation proved to be an intermediate generation. The fifth generation wind turbines had 15 to 17 meter rotor blades with sizes between 300 and 400kW. The sixth generation had a capacity between 450 and 750kW with rotor blades between 18 to 22 meters. Around 1997, the seventh generation was introduced to the market with sizes from 800 to 1000kW and rotor blades from 25 to 27 meters.

demonstration projects, additionally the capabilities gained through the build up of C-WET have been very important for the development of the Indian wind turbine industry.

Conclusions

Despite having developed in very different national and cultural contexts, many important actors within the wind turbine industries in Denmark and India have cooperated, to the benefit of both parties. The effect of this interactive learning process on the development of the Indian wind turbine industry has been substantial, but has without a doubt also benefited Danish firms in their efforts to establish themselves in a growing market outside Denmark.

This paper highlights the role of technological policy and institutions in determining the success or failure of industrial development. A special emphasis is put on the role of interactive learning in the success of the Indian wind turbine industry. The comparative case of wind energy in Denmark and India demonstrates the importance of finding the right institutional and policy setup for each country is not a matter of copying the 'best' policy and institutions but of finding the matching setup for the relevant context. For this purpose, a policy of interactive learning with other actors is an option that has not been emphasized before.

Interactive learning between Danish and Indian actors at the government, firm and policy levels has had a high impact on the development of their wind turbine industries. At the government level the early efforts to establish the Indian wind turbine demonstration projects had an important effect in attracting private investors to wind energy projects. The cooperation programme between the Government of Denmark and the Government of India to establish Indian wind farms and production facilities provided the basis for the growth of an emerging industry. At the firm level we see the strong presence of Danish firms in the Indian wind turbine industry. In 2003 Danish firms had a 38.1% market share in India. LM Glasfiber, the leading rotor blade supplier, has also established itself with its Asian base in India. The strong presence of Danish firms in the Indian wind turbine industry is now being matched by Indian manufacturers. Suzlon, the largest Indian wind turbine manufacturer has recently established its international headquarters in Denmark due to its base of wind energy expertise and extensive network of component suppliers (WPM, October 2004:25).

At the policy level we see similar emphasis being made in both Denmark and India. Examples of this include the high awareness of the importance of having stable policies, as well as an emphasis on importance of utilities and grid connections for the early development of the industry. Additionally, in Denmark a combination of early R&D efforts and stringent certification standards, were the primary policy drivers in developing a large wind turbine industry. This practice has been transferred to India through the establishment of C-WET. As a result India is now one of the three world leaders in certification and testing of wind turbines, despite being a developing country.

India's policy of attracting world class actors to advance its emerging wind turbine industry has without a doubt contributed substantially to its successful development. India is now by far the most successful developing country in wind energy and is the fastest growing one worldwide.

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