Answers in the Wind: How Denmark Became a World Pioneer in Wind Power

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It is not surprising that countries around the globe are closely watching the development of the wind power industry in Denmark. The country has acted as a pioneer of both new technologies and innovative government approaches ever since wind power first began to be viewed as an alternative energy source in the 1980s. There is now a general consensus that one of the most important elements in the development of wind power has been active governmental policy. Clear policy goals established in Denmark's energy plans have given confidence to potential players in the wind power sector, and a subsidy scheme for installation of wind turbines developed in the 1980s gave vital support to the industry in a period when wind turbine project costs were not yet competitive with other energy sources.

Later, in the 1990s, a fixed pricing system for selling electricity to the national grid gave investors further stability and confidence. Continued technological development reduced costs, which resulted in Denmark reaching its goal of obtaining 1500 megawatts (MW) of power from wind by 2005, five years ahead of schedule. The fact that private individuals and cooperatives could connect turbines and sell electricity directly to the national grid resulted in more than 80 percent of the wind power installations in Denmark being owned by private individuals. All of these factors have led to the high degree of acceptance wind power receives in the country.

As in many other countries, Denmark also has supported research and development (R&D) in wind power. But where other countries have primarily looked at large-scale turbines to be built by major electricity companies, Denmark has supported the development of smaller wind turbines. The amount of money spent on R&D in Denmark has not been large compared to many

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other countries. Since the mid 1970s, however, constant support has been given to a variety of different projects and consequently a capacity has built up at Danish institutes, especially at the Risoe National Laboratory. Today Risoe is one of the world's leading institutes of wind power research, providing tremendous value for manufacturers and enabling the number of commercial wind turbines to grow more than 100 times worldwide in just a few years.

The Danish success is the result of a variety measures that have helped push the average turbine capacity from 20 kilowatts to 2 megawatts in the past 20 years. The key message from Denmark to the rest of the world is that success depends on both a firm policy sustained over the longer term, as well as sufficient government support to overcome the extra cost of the first installations. Fortunately, with the technology having already been developed, no countries will have to start from scratch.

THE STATUS OF WIND POWER IN DENMARK

Wind energy today provides 14 percent of Denmark's electricity consumption. More than 6,200 wind turbines with a total capacity of 2,350 MW have been erected since the early 1980s. Technological development during this period has been spectacular, bringing down production costs of each kilowatt hour (KWh) by more than 300 percent since the 1980s in terms of current prices. More than 80 percent of the 6,200 wind turbines in Denmark are owned by wind energy cooperatives or individual farmers. Some 150,000 Danish families own wind turbines or shares in wind cooperatives. Danish wind turbines account for half of the world market, with a turnover of some $1.6 billion in 2000 in a total market of over $3 billion. From 1994 to 2000 the wind industry grew at a rate of some 40 percent per annum, and growth rates of around 20 percent per year—comparable to growth rates in the computer and cell phone industries—are forecast for the first decade of the new century. In 2000, Danish wind-turbine companies supplied turbines with a rated capacity of some 2,100 MW, equivalent to two large nuclear or coal-fired power stations per year. Wind-turbine manufacturing, maintenance, installation and consultant services currently account for some 16,000 jobs in Denmark, while component supplies and installation of Danish turbines currently create another 6,000 jobs world-wide. All in all, the facts on Danish wind power are impressive. How did this success come about, and what are the lessons learned?

WIND AND RENEWABLE ENERGY POLICY

Denmark was extremely dependent on imported oil in the early 1970s and pursued an active policy of increasing energy savings, boosting self-sufficiency

and diversifying energy sources through the mid 1980s. Since then, energy policy has increasingly promoted the use of renewable energy to ensure environmentally sustainable economic development.

Long-term planning was considered particularly important, and when the government created "Energy 21," its energy action plan, it created a planning horizon set at the year 2030. The reason for this very long-term planning is to ensure consistency in policy and to send strong signals to market actors about the policy scenario in which they will operate. In the electricity sector, plants and equipment have long lifetimes, with transformers, transmission systems and generating plants, for example, remaining in service for up to 50 years. One important aspect of current planning is to ensure that the future electricity system will be able to accommodate a very large amount of power from intermittent renewables.

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During the past 15 years, the Danish government has pursued a target of ten percent wind energy by 2005. This target was achieved last year. A new target has now been set for 20 percent of Danish electricity consumption supplied by renewable energy by 2003. The majority of this energy is expected to come from wind power and this target might even be met earlier due to high installation rates of new capacity in 1999 and 2000. The ambitious government plans in the Energy 21 policy document indicate that around 50 percent of Denmark's electricity consumption should be supplied by wind energy by 2030, largely achieved through new offshore wind turbine installations.

MUNICIPAL PLANNING

The policy of installing 1,500 MW of installations onshore in Denmark has been a challenge for municipal and regional planners, given the country's high population density. For the past few years, Danish municipalities have been required by a planning directive from the central government to make plans to install wind turbines.

Although no specific quotas were set by the government, most counties have required municipalities with good wind resources to provide suitable sites for turbines. To assist municipalities in carrying out planning for wind turbines, a national wind map, based on rough, manually prepared estimates, was made available in 1991. After the recent round of planning, with extensive hearing procedures for local residents, sites for more than 2,600 MW have been made available.

THE ROLE OF POWER COMPANIES

Deregulation of the energy sector has been a key issue in Denmark, as it has been internationally. The energy reforms currently being implemented aim at reaping the economic benefits of increased competition and free supplier choice while simultaneously supporting environmental objectives. To do so, the government has introduced new and innovative measures to achieve environmental goals under the new market conditions that liberalization has brought.

Historically, the government has had wide-ranging and direct powers to regulate utilities. Power companies now, however, are operating on the basis of completely new legislation. The challenge has been to transform a monopoly under tight governmental control into a set of independent companies that can face international competition and help the government to pursue its environmental goals. For this purpose, new measures working in conformity with market conditions have been introduced. A green-certificate market will enter into force by 2003 with the purpose of securing further cost-effective expansion of renewable energy in electricity production, and carbon dioxide emissions trading has already been introduced for the electricity sector. Utilities have also been ordered to install 400 MW of wind power onshore. The first two orders of these installations, providing 100 MW of power each, were issued in 1985 and 1990. The latest onshore order for 200 MW to be completed before the year 2000 was issued in 1996. In 1998, a new order was issued for 750 MW of offshore wind power. While, the Danish development of wind power could probably have been carried out with private investment (i.e. with non-power-company investment) alone, as it has been in Germany, the primary advantage of power-company participation from a political point of view has been to ensure that expertise and commitment to renewable energy is present within power companies.

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The improving economics of wind energy have changed attitudes. Power companies today realize that wind is the cheapest option for meeting statutory environmental requirements that are likely to remain on the political agenda for the foreseeable future. In this situation, the power companies have urged that the government leave wind development exclusively to power companies because the present energy-tax refund system makes it far cheaper for power companies to produce their own wind power than to buy it from independent generators. The average cost for power companies' own wind generation is between 0.28 and 0.34

Danish kroners per KWh ($0.04 per KWh). The strengthened commitment of Danish power companies to wind energy is exemplified in their eagerness to develop the first 750 MW of offshore wind power; applications for planning permission were launched even before the actual government order was issued.

INVOLVEMENT OF SCIENTISTS

In order to ensure that government-subsidised turbines also had a certain level of quality and safety, an approval scheme for wind turbines was established. Responsibility for the scheme was given to the National Laboratory at Risoe, which was originally established to do research on nuclear power. While most nuclear research has since been abandoned by Risoe, the institution today has an important research department for wind energy, with some 50 scientists and engineers employed in research on aerodynamics, meteorology and wind assessment, structural dynamics, and advanced materials. Risoe has arguably been the foremost international research institute for basic research into wind-turbine technology and wind-resource assessment since the early 1980s.

As early as the late 1970s, Risoe National Laboratory was charged with the approval of wind turbines installed with public investment grants. The approval process was extremely useful for weeding out low-quality and potentially dangerous products, and put pressure on manufacturers to upgrade their design and manufacturing skills.

Risoe's very strict safety requirements, which include demands for physical testing of rotor blades and conservative norms for load calculations, indirectly saved Denmark's core manufacturers from the fate of many foreign competitors whose turbines collapsed in the early days of the industry. The potential for weight saving was obvious and Danish wind turbines have shed half their weight per kilowatt of power installed during the past five-to-ten years, despite a 50 percent growth in their physical size.

There has been considerable interaction between Risoe and the wind-energy community worldwide. Risoe's work on turbine safety has been important in ensuring the reliability of modern wind turbines. Danish turbine manufacturers guarantee a 98 percent availability rate for their turbines, and statistics show that, in practice, the availability rate is around 99 percent.

MARKET DEVELOPMENT SCHEMES

In the early 1980s, the Danish government instituted a number of successive market development schemes. It originally funded 30 percent of the investments in new wind turbines, though it gradually lowered this rate until support was abandoned in 1989 (by which time subsidies had fallen to ten percent).

Government also intervened to obligate power companies to purchase energy produced by wind turbines. Originally, the pricing arrangement for selling the electricity was negotiated between the Danish Wind Turbine Owners' Association and the Association of Danish Power Companies. In 1992, however, the power companies terminated the agreement, and subsequent negotiations with the turbine owners failed to reach a compromise. After this, the government and Parliament intervened and passed a general law on renewable energy that included a purchasing obligation, requiring power companies to pay for electricity from privately owned wind turbines at a fixed rate. Until 2000, the rate was 85 percent of the local, average retail price for a household with a (high) annual consumption of 20,000 KWh. The electricity price paid by power companies for wind energy from privately owned wind turbines varies between 0.25 and 0.35 kroners per KWh ($0.036 to $0.05 per KWh), reflecting the varying prices of electricity from different local distribution companies.

Since 1992, in addition to the price paid by the power companies, wind-turbine owners have received 0.27 kroners per KWh of power. This pricing system is now being changed to a market system, where new turbines in the future will receive a market price from the power company, plus green certificates which can have a value of between 0.10 and 0.27 kroners per KWh. This change should be seen as recognition of wind power as a proven technology for future electricity markets.

CAN THE DANISH INDUSTRIAL SUCCESS BE REPLICATED?

While much can be learned from the wind energy experience gained in Denmark, the country's success would not be easy to replicate elsewhere, and it certainly would not be easy to replicate in the same manner. Technology development is different, markets and competition are different, and the political environment is different. In some sense the Danes were fortunate enough to be in the right place at the right time with the right concept.

Developing a wind market from the ground up is much more difficult today, especially when the largest market segments have tougher competition, with more mature and reliable technology. The same market segment requires large machines with larger capital requirements and higher development risks. Furthermore, there are currently no fundamentally revolutionary turbine technology concepts in sight—that is, no demonstrably economically superior technologies, although there are many options for further development and cost cutting within the major variants of present technology.

Most modern wind turbines tend to be three-bladed designs with the rotor position maintained upwind (on the windy side of the tower) using electric motors. This design is known as the classical Danish concept, and has become the benchmark for all turbine designs.

Manufacturers in several countries have chosen to link up with Danish manufacturers in a variety of joint ventures. This coupling has included significant technology transfer to local companies. The primary advantage of a technology link to an existing manufacturer is to acquire proven technology, and the opportunity to offer a more complete and continuously optimised model range. The Danish domestic market originally created the modern Danish wind industry, and gave it the testing ground to organize both wind technology and manufacturing technology, including the important issue of quality control.

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Denmark is arguably unique among wind-turbine markets. The market grew out of a popular interest in alternative generating technologies, partly in opposition to the use of nuclear power, and partly as a result of the energy crisis in the late 1970s.

When interest in wind energy exploded in California in the early 1980s, creating what some have called "the Great California Wind Rush," Danish companies were, practically speaking, among the only firms in the world with a substantial track record. The result was that investors tended to prefer Danish machines, which ultimately made up roughly half of the capacity installed in California. The importance of the learning harvested by the major Danish manufacturing companies from manufacturing thousands of machines for the California market cannot be overestimated.

Private individuals, either as members of wind energy co-operatives, or as owners of wind turbines (such as farmers) account for about 80 percent of installed wind-power capacity in Denmark. Wind co-operatives are organised as unlimited partnerships, but since the turbine and its installation are usually completely paid up, partnerships have no loans and no (joint) risk in this respect.

In contrast to Germany, Sweden, the United States, Canada, and the UK, publicly financed R&D projects played a relatively minor role in initiating the early development of the Danish wind turbine industry. The early stimulus came in the form of investment grants supporting market development for small-scale, privately owned turbines.

Since then, the Danish government and the European Union have financed a significant number of basic research projects and given limited support to development projects. It is estimated that a staff of 60 to 80 people in Denmark (including both researchers and administrative staff) work on publicly financed R&D. Danish wind turbine manufacturers together have a staff of about 100 people working on technology development. Total public support for this work is less than 2 million per kroners year.

LESSONS LEARNED

Although it might be difficult to enter a mature wind-power market, the Danish story provides valuable lessons for the future development of new environmentally friendly technologies. First and foremost, the Danish experience shows that *it can be done.* Determined, long-term political commitment can bring down costs and create new markets for technologies supporting sustainable development. Technology support must be both careful and focused—on both ever-changing market conditions and technology needs.

Secondly, Denmark has shown the wind power *can be done at a low cost.* Early action allows sufficient time for a gradual and parallel development of the technology and the market. Costs are not wasted on a forced research-and-development path without the proper market underpinning. Market deployment is as important—if not even more so—as research and development. Finally, patience has rewards in a rapidly growing market.

FUTURE PERSPECTIVES

Wind turbines have grown dramatically in both size and performance in the past 15 years. The early machines that produced just 25 KW of power generated by rotors with diameters of 10.6-meters can still be found in Denmark, but they are quickly becoming anachronisms. Today, the most widely sold turbines have a rated power output of 750 KW to 1000 KW, and rotor diameters of 48 to 54 meters. The largest machines commercially available are 2,500 KW machines with rotor diameters of 80 meters on 70 to 80 metre towers. Each 2 MW machine produces more energy than 200 of the vintage machines from 1980.

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The coming two decades of wind power promise to be as exciting as the last two. In Denmark, the future development will be offshore. Although replacement of old turbines leaves room for increased capacity, there is, in fact, very little space remaining on land for new installations. Offshore wind energy, however, could make a significant impact on the emission problems related to conventional power-generation technologies. This is partly because the offshore wind resource base is vast and consistent, and partly because the technology is now cost competitive. This move to offshore wind power also opens a new frontier of technological challenges. Further increasing the sizes of wind turbines,

already the largest types of rotating machinery on earth, will be a challenge for manufacturers. Other challenges involve the need for mass production of cheap foundations, and for improvements in the logistics of installation, surveillance, and maintenance. None of these factors, however, will thwart the growth of the industry. The proof of that hypothesis will be visible in the seas around Denmark: There you will see first large-scale offshore wind farms in Europe, creating a powerful and steady stream of the most renewable energy on earth. ■