Industry Formation and State Intervention: The Case of the Wind Turbine Industry in Denmark and the United States

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Abstract

In some situations a strong case can be made for state intervention into the process of industry formation, the so-called baby industry argument. The formation of the wind turbine industry in both the US and Denmark represents case where national governments decided to help in the formation of the wind turbine industry.

The form of intervention is crucial to the outcome. Two forms of intervention and their results are analysed in this paper. The bottom-up, market-driven approach in Denmark is compared to a top- down, research and development oriented approach in the US. The analysis clearly underlines the supremacy of the bottom-up, market-driven form of intervention.

The present paper unveils the historic development of the wind turbine industry in the United States and Denmark respectively and contrasts the two experiences, which has lead to two very different outcomes. In the US, the technological development basically resulted in nothing more than a shaky industry and 5,000 pages of research results. In Denmark, however, the development resulted in the formation of several strong companies and the development of an industrial cluster, which today accounts for almost 50% of a US$ 4.5 billion global wind turbine market.

Introduction

Wind has been harnessed to do man's work from ancient times. Along with water power, wind is the oldest source of power known to man. The ancient Asian civilizations used wind power and it is said that Hero of Alexandria described a simple wind turbine.The technology was generally known in Europe since the Middle Ages. (Andersen 1999) Vestergaard, Brandstrup and Goddard (2004) have compiled a brief history of the development of wind turbine power generation in Denmark and the United States. Our interest in this paper is to examine how the wind turbine industries in Denmark and the United States have taken such divergent paths. Specifically, we will look at the influence of state intervention in this fledgling industry, and specifically the nature of the forms of intervention and the outcomes of the interventions.

Development Strategies

Many research and development programs were started with governmental support and private sector activity in wind energy also slowly emerged. But the national governments in Europe and in the US used several different approaches to promote wind energy. While some countries put considerable capital and effort into large R&D programs, others concentrated on creating the right market conditions for deployment of the technology. (Bourillon 1996)

Development strategies are usually split up into two main categories based on whether they are driven by technology development and research or market driven. A classification rooted in the discussion of the relative importance of market dynamics (market-pull) and technological innovations (technology push) in industry development – a classification that is quite descriptive of the actual strategies introduced for the development of the modern wind turbine technology in Denmark and the U.S. in the 1970s. (Karnøe & Jørgensen 1995)

According to Peter Karnøe, two development theories for the production of wind turbines took place during this period – the top-down strategy and the bottom-up strategy.

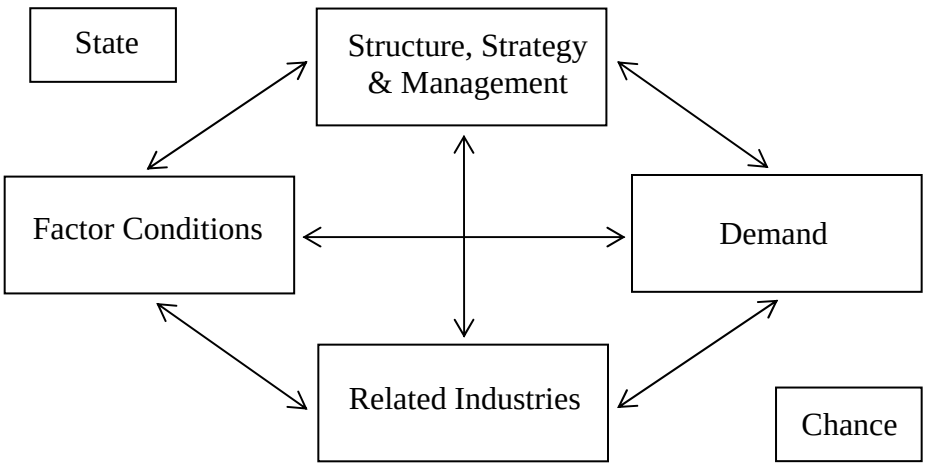
In the top-down strategy the development aspired to achieve fast technological advances and radical innovations regarding the size and efficiency of the wind turbines. It was based on national "Science-technology push" policies and therefore characterized and controlled by restricted governmental programs or institutions, which financed development contracts to "promising" companies. The relationship between science and technology was hierarchical in the sense that a basic scientific knowledge was seen as the most important factor in developing the new technology quickly. The development teams in this approach were therefore characterized by scientific competencies with a theoretical orientation. (Karnøe & Jørgensen 1995)

The bottom-up strategy, on the contrary, was characterized by national "market pull" policies and contained less radical innovations and gradual technological improvements directed towards an actually existing market (it is nevertheless open for discussion whether or not the activities were fully

market driven as the market for many years was subsidized as well as the fact that a lot of the research was funded from allocated resources from state programs). In this strategy the relationship between science and knowledge was more balanced in the sense that they were seen as interdependent factors in developing new technology. The players in this approach were more practical engineers and skilled artisans who already possessed technological knowledge in the area. (Karnøe & Jørgensen 1995)

As indicated in the previous sections, the US has predominantly followed the top-down strategy and more or less from day one focused all research on the development of large wind turbines in the belief that only these could have an impact energy-wise and deliver the cheapest energy due to economies of scale. Denmark, on the other hand, predominantly followed the bottom-up strategy and started out with small and medium-sized wind turbines, which were gradually improved and enlarged. For this type of wind turbines there was already technological and operational experience in Denmark, which meant that the wind turbine industry got off to a head start.

The following sections will illustrate the development in light of these strategies in more detail. But in order to identify the main factors that may have influenced the two very different paths that the wind power industry took in the two countries, the development is also illustrated in the light of Michel Porter's "Industry Diamond". Porter believes that technological development and competitive advantages are a result of "improvement and innovation in an industry that are never ending processes, not a single, once-and-for-all event." (Porter 1990) The Diamond serves to explain the long-run development of a country's international competitive position, which is created on the basis of the individual nation's own unique characteristics. The model is probably the best-known analytical tool for understanding the development and the attractiveness of an industry and entails those values, which, according to Porter's research, are important in gaining a national competitive advantage. The diamond and its factors are illustrated below:



The four main factors, *Factor Conditions, Structure, Strategy & Management, Demand and Related Industries*, are all interdependent and together form a picture of the attractiveness of a given industry. In addition to this State and Chance – factors which are out of the company's and/or the state's control – may also have an impact on all factors in the diamond and the competitiveness of the industry.

As mentioned earlier, Michael Porter ascribed the Danish success to different factors in the environment – factors which are all part of his theoretical "Diamond". The following comparison of the industrial developments in the U.S. and Denmark will therefore be described and analyzed in the light of Peter Karnøe's two development strategies and the above framework of Michael Porter.

Denmark

The two oil embargoes of 1973 and 1979 and the awakening green movement in the Western societies gave a real boost to the Danish wind turbine industry and set the stage for the present era of wind power. The politicians realized the country's dependence on oil which at that time constituted approx. 90% of the energy consumption and a governmental commitment to the development of wind power in Denmark has continued more or less undisturbed ever since, although the governmental financial support to wind power has been questioned, especially from the traditional industrial society, after the stabilization of fossil fuel prices during the 1980s.

Factor Conditions

The factor conditions are divided into physical and human resources; the first of which consisted of the natural resource of wind – an abundant "raw material" in Denmark due to the country's long coastline and thus a prerequisite for the development.

Regarding the human resources – one of the most important factor conditions in Denmark was the old smith industry and tradition of building wind turbines, which started in the late 19th century. It all started as private/individual experiments, some of which were more successful than others. These individuals were primarily skilled artisans and engineers with previous experience from the machine- and smith industries. The major difference in their approach compared to the American developers was that they started out building small wind turbines and gradually improved these, whereas the Americans right from the beginning operated with quite large wind turbines.

There was a lot of know-how and experience built into the industry and many well-educated people who could take advantage of their skills in this new business area. Both researchers and manufacturers therefore utilized their existing competencies and skills in the building of the wind turbines and the competencies they did not have in-house were available from sub-contractors who were on the lookout for new business areas to carry their businesses through the ups and downs of the business cycle.

The Political Environment

The conditions for the Danish wind turbine industry were considerably improved during the 1970s. The energy policies, which were hot topics in this period, were closely associated with environmental policies and the rising green movement was just another push in the right direction in the search for renewable and non-polluting energy sources. The grass roots coordinated themselves in organizations like *Organisationen til Oplysning om Atomkraft, OOA* (The organization for information on nuclear power), the environmental organization *NOAH* and *Organisationen for Vedvarende Energi*, OVE (The organization for renewable energy sources). Suddenly wind energy was associated with an ideology that many could identify with and thus support.

In addition to the founding of grass-root and interest organizations for the environment and renewable energy sources, branch unions were established. The test station *Risø* started wind power research, which was under much controversy as Risø was originally the center of all nuclear research and the passing of a government sponsored subsidy scheme for the construction of new wind turbines improved the economic conditions for the industry as well.

The Risø test station was established in 1978 and would prove to have a considerable impact on development in the industry. The initial purpose was to help develop wind turbines for industrial production within a period of three years. If it did not succeed it would be closed down again and if successful it would still be closed down but moved to the Danish peninsula of Jutland where it would carry out standard testing for the manufacturers. Risø's problem, however, was that all knowledge about the practical production of wind turbines was in the heads of a few self-taught manufacturers in Jutland. In the early years it was the industry itself, which drove the development forward, while Risø more or less stood on the sideline observing the development and assimilating all existing knowledge.

With time, however, the role of Risø became increasingly important. In 1979 the Danish government decided to introduce a governmental subsidy of 30% of the installation price for wind turbines, which undoubtedly pushed the development forward. In order to get the subsidy, however, the design of the turbine, the tower, the base and the electrical system, had to be approved from test station Risø. The manufacturers had to let the people from Risø in on their deepest industrial secrets and many were, for obvious reasons, quite reluctant to show these potential "government spies" their designs. But there was no way around it and gradually Risø managed to win the trust of the manufacturers and the test station gradually acquired knowledge on which basic designs were most effective and reliable. This knowledge helped lift the criteria for which approval of the machines relied on and improved the quality of the Danish wind turbines drastically. In addition to this the Gedser turbine was refurbished in 1975 at the request of NASA in order to run a test program for the American Department of Energy. These tests proved that the basic principles in the old turbine were so good that they were actually recommended and later on formed the basis of Risø's

quality standard and certidication of Danish wind turbines for which they later would become world known (*Vindinformation 2002*).

The role of the test station evolved from being purely controlling to becoming an active participant in the technological development, and in 1982 the test station developed a capacity paradigm for wind turbines stating that all components should be dimensioned to be twice as powerful as the traditional norm stated. As simple and primitive as this may seem compared to the high-tech wind turbine constructions abroad – this standard certification and the standing requirements from Risø are some of the major reasons for the success of Danish wind turbines in the world market. The turbines were simply more sturdy and able to withstand the power of strong winds and therefore more reliable than other foreign designs. (Jensen 2003)

From the beginning, the primary political objective of producing wind turbines has been to increase the supply of electricity from renewable sources. Since the early 1980s, production of electricity from wind turbines in Denmark has been stimulated by various environmental policy motivated state aid schemes, among which the most important has been a price guarantee per produced kWh (kilowatt-hour) to the producers of wind energy – that is the wind turbine owners. (Morthorst 1999) Every wind turbine owner has the right to deliver electricity to the main net and receive a fixed guaranteed price per KWH. All electricity consumers paid for the cost of this arrangement. The arrangement established a market for wind turbine electricity and focuses the market's attention on the cost efficiency of the turbines. Without these subsidies wind turbines as suppliers of energy would not have been competitive compared to the traditional power plants and other energy sources. This meant that without these subsidies th

Following the Californian wind-rush (see later section) a wave of bankruptcies flushed the industry and the government decided to turn the investments in wind energy from being a hobby-investment in cheap electricity to being more power station oriented. It was legislated that private investors no longer could build wind turbine parks around the country and that as an investor you had to live within a radius of 10 km of your turbine; a decision that was widely supported by the public. In addition to this, the subsidies and the attractive tax schemes were cut completely. The manufacturers in the industry and the investors could no longer make the wheels turn on the basis of these contributions but had to rely on true wind energy alone. Just like any other industry, it was time to deal with market forces and international competition.

The government also directed the power stations to erect wind turbine parks with a total output of 100 MW over a 5-year period – a doubling of the installed wind turbine output at that period. It took 8 years for the power stations to fulfil this demand, but in spite of the new restrictions private investors managed to install twice the capacity within this period. In a time when the manufacturers were struggling to survive the breakdown of the US market, the governmental regulations on the power stations and the backing from the public helped keep the Danish production alive. (Jensen 2003)

The early support for alternative energy sources from the Danish government created a big home market for wind turbines and gave the Danish manufacturers first mover advantages in the world market. These advantages, however, could not have been as successful without the existence of an extensive learning-by-doing within the industry, which reduced the production costs further and consolidated the competitive advantages of the industry. (Masden 2002)

Researchers and Manufacturers

Research in wind power utilization did not disappear and die due to the intense competition of fossil fuels in the 1950s and 1960s. The revival of the wider interest in wind power during the 1970s did not start from scratch, but was built on a solid foundation of theories and practical experiences. The research was primarily in cooperation between government-sponsored research institutions such as the Risø test station and many small and medium-sized private enterprises.

One of the more influential programs in the description of the development of modern wind turbines in Denmark was the example set by the Tvind Folk School (The Traveling Folk High School) in Jutland. The charismatic leader Amdi Petersen and his associates created the idea; the students and teachers at the school who had no experience with wind turbines whatsoever erected it but it was the technicians from the surrounding community that made it possible to complete the project with reasonable success. And what the wind turbine was missing in regard to technical visions it definitely had in its symbolic importance. It was a darling of the media and became a great source of inspiration to many of the people who later became responsible for the development of the Danish wind turbine industry.

This also illustrates the fact that the development at this point in time was primarily based on experiments of individual players with very different backgrounds. Many were skilled artisans and engineers carrying knowledge from the machine- or smith industry and their main motives were to control their own energy supply and take advantage of the free resource of wind.

Soon after the oil crises in 1973 an economic slowdown followed and many companies were threatened by cutbacks and financial stagnation. They were therefore forced to think innovatively and look at other options in terms of new product areas and markets in order to survive. Inspired by the experiences of the early pioneers many company-entrepreneurs started looking into the wind turbine industry and the possibilities of transforming their knowledge and experience into manufacturing of wind turbines in their existing companies. Some of these entrepreneurs succeeded and it is during this period that many of the large Danish wind turbine manufacturers, which have a great impact on the wind turbine market today, were established.

Nordtank, today merged into NEG Micon, was originally a manufacturer of road tanks for the oil industry but decided to utilize its experience in working with steel and designed its own wind turbine. The same situation occurred for Vestas – a former blacksmiths workshop – that utilized its

know-how in machine production to make wind turbines and for Bonus, which utilized its know-how in accessories to agriculture. Common to all these pioneering companies was that they could benefit from their existing competencies and know-how on basic smiths work, which is an integral part of the manufacturing of wind turbines. More importantly, however, they all also had charismatic entrepreneurs and leaders who believed in the future of wind energy and had the vision, backbone and determination to pursue their dreams.

A quick dispersion of knowledge within the Danish industry took off, enhancing the competition and the development of superb wind turbines. A dispersion which seems to be rooted in the close cooperation between government and manufacturers and a historic tradition of knowledge sharing and helping each other in the old blacksmith-environments in Jutland. Many companies branched out into wind turbines – only to over expand and plunge into financial near-collapse when the incentive system was suddenly cancelled in the mid-1980s, which brought almost all manufacturers to near bankruptcy.

Vestas was one of these bankrupt companies and was bought by a small group of local investors in 1986, which believed that the company had a good reliable technology. It decided to focus on the company's reputation as the most reliable manufacturer of wind turbines – the Mercedes Benz of the wind business – giving the company a two-decades head start over other competitors. After the crack in the early 1980's, which had created an impression that wind turbines did not work well, Vestas built a test site in California and the turbine performed well and eventually the market started to revive. An upward trend – the California Wind Rush – started which would save the Danish top manufacturers from bankruptcy and shutdowns.

The California Wind Rush (Chance)

The first significant commercial market to appear was in California, which, in the period between 1980 and 1986, helped the international wind energy industry to develop. The big turning point for many of the Danish manufacturers came in 1982 when an exploration of the American market confirmed that a basis for "something big" existed – some people even claim that the modern wind turbine industry was born in California. The governor, Edmund G. "Jerry" Brown, was an environmentalist who, having been affected by the large electricity supply problems and increasing environmental problems, started an aggressive energy policy in favor of renewable energy sources favoring the market for wind turbines and kick starting the young industry.

With support from the Council for Technology and its pool of resources for export-promoting initiatives it was possible to send a Danish consultant to carry out the basic market research. He came home with information that convinced the Danish industry that there definitely was a large potential in the US and in California in particular. All of the large wind turbine manufacturers immediately rushed to the other continent and came home with orders in sizes that were not even possible in the

small domestic market but which made it possible for the manufacturers to start batch production of wind turbines. (Kolding 2000)

The beginning of the Californian wind adventure could have ended as fast as it started – the investment incentives were simply too good and for some it seemed to be more an investment in tax deduction than in alternative energy. In addition to this many investors complained about unreliable prospects as many of the wind turbines broke down after only a few weeks or could not produce what had been promised. The entry of the Danish manufacturers would turn out to be the rescue for the Californian program – the market was desperate for reliable wind turbines and coupled with an attractive tax program, billions of dollars of venture capital and a high dollar rate, the two worlds – although separated by a great ocean – were created for each other. (Jensen 2003)

Manufacturers from Denmark, the United Kingdom, Germany, Japan and the Netherlands shared the market in California with several American companies. About 15,000 wind turbines were installed in California during the 1980s, of which almost half came from Europe, mainly from Danish manufacturers. During that period of time the size of the average wind turbine generator increased from 55 kW to 100 kW. (Bourillon 1996). The Danish innovators of the new wind turbine technology were the pioneers behind this development, and Denmark succeeded in acquiring a first mover advantage.

The end to the fairytale of the export boom came in 1987 with the falling prices of oil, a decreasing dollar rate, and decreasing political interest. Many environmental groups were annoyed with the wind turbines – some places they were standing too close, other places were filled with wrecked wind turbines and dead birds. Worst of all, were stories of people who had lost their savings in doubtful projects where the wind turbines did not live up to the prognoses the investors had been promised. In addition to this energy was no longer a problem.

A wave of bankruptcies swept the Danish industry off its feet. In the months before the manufacturers savagely fought over the few remaining export orders. Out of about 100 American developers only Zond and Kennetech were left – and both were financially unhealthy. All manufacturers in Denmark were closing down and almost 10 years of know-how was in danger of disappearing. The reconstruction of the industry would take several years and several old industrial companies entered as joint owners of the wind turbine factories. This supplied the industry with a necessary professionalism on top of a build-up period, which had been characterized by an almost euphoric entrepreneurial spirit, where financial and quality control was in low priority. (Jensen 2003). Vestas, Nordtank and Micon had new capital injected and a new management brought in. They slowly rose again and after a period it was clear that these companies and Bonus would survive and remain the core of the Danish wind turbine industry.

Related Industries

At the end of the 1970s and the beginning of the 1980s a well functioning network of subcontractors supplying wings (blades), control systems and gears was established. One of the most remarkable stories is that of LM Glasfiber.

None of the Danish wind turbine manufacturers, except from Vestas, manufactures their own wings. For many years the dominant supplier of wings was Alternegy but following the breakdown of the Californian market this company went bankrupt in 1986. The hole left in the business was a given opportunity for a breakthrough for LM Glasfiber. This company had earlier tried to manufacture wings but without any success. The company was known for manufacturing sailboats made from fibreglass but had always had many different products at the same time. And when they were asked to manufacture wings they honestly did not expect it to amount to anything big.

The early projects were not successful but eventually – after having sold some of its shares to Vestas, who was booming in America – everything changed. LM Glasfiber functioned as a buffer to Vestas who manufactured its own wings. When Vestas folded, LM Glasfiber bought back its shares and became the only manufacturer of wings in the market. This monopoly saved the company which had left its other business areas in order to focus on fibreglass wings and when the orders later on poured in from the remaining wind turbine manufacturers LM Glasfiber could more or less control the market as it pleased. The only competitor was Dutch Airpac but its wings were neither cheaper nor better and the manufacturers generally preferred a Danish supplier.

Many suppliers have succeeded in achieving a quite considerable integration over the years. Most wind turbine producers have a long tradition of close cooperation with a few suppliers of individual components, but due to the fact that the manufacturers produce more and more components in-house the suppliers are increasingly being squeezed by the wind turbine industry.

The Public (Demand)

As mentioned earlier the green movement started in the 1970s as a result of the energy crises. The oil embargo, price increases and the political measures had an enormous impact on the public's attitude towards energy and energy consumption, which until then had not been an issue at all. People suddenly became more aware of the environment, and energy and environmental policies became hot topics and were heatedly debated in the media, in the workplaces as well as in private homes in Denmark.

More and more people were in favour of renewable and non-polluting energy sources and started to organize themselves in organizations and support groups. Wind energy was associated with ideological elements and thoughts, which many believed in and supported.

Wind turbine owners organised themselves in *Foreningen Danske Vindkraftværker* (Organization of Danish Wind Power Stations), whose monthly publication "*Naturlig Energi*" (Natural Energy) had a substantial impact on the development in the industry as it passionately described the development in wind energy and brought monthly statistics on how much energy the individual wind turbines (brand, type and localization) produced creating a uniquely transparent market from the beginning. (Jensen 2003) For existing and future wind turbine owners this was a fantastic opportunity for evaluating the quality of the different wind turbines, which probably also had an impact on which of the many manufacturers were able to survive in the long run.

Usually big investors finance wind energy projects, but Denmark has shown that a different model is possible, through the formation of local guilds and non-profit partnerships of wind turbine owners, who pool their capital investment in local wind turbines. In 1999, 50% of Denmark's 3,200 turbines were owned jointly by 67,000 guild members, bringing significant economic benefit to Denmark's rural areas. The other 50% were individually owned.

The development of the industry has been greatly affected by this positive encouragement from the public. The Danish population has supported the national wind turbine industry almost from day one and through their support and investments created an environment and national market, without which the manufacturers probably could not have survived.

The United States

In the U.S. the interest for wind power had waned until the early 1970s but following the OPEC Oil Embargo of 1973, interest in wind energy resurfaced in response to climbing energy prices and questionable availability of conventional fossil fuels. Federal and state tax incentives and aggressive government research programs triggered the development and use of many new wind turbine designs and in the 1970s there were nearly 50 domestic wind turbine manufacturers in the U.S compared to only one after 1986. (Karnøe & Jørgensen 1995)

Factor Conditions

Just as in Denmark, the physical factor condition – that is the natural resource of wind – was also present in the US along the coastlines and the mountain passes. The first prerequisite for the development therefore existed. As to the human resources one of the Americans most important factor conditions was a large base of professional scientists and a large aircraft industry, whose technology to some extent is closely linked to that of wind turbines.

The Political Environment

The federal government's involvement in wind energy research and development began in earnest within two years after the so-called "Arab Oil Crisis". Until the 1970s, all federal research in energy

had been concentrated in the Atomic Energy Commission (AEC), which primarily concentrated on the country's use of nuclear energy for nuclear weapons. The oil crisis, however, had shown that there was a need for alternatives to the conventional forms of energy.

The Federal Wind Energy Program had its beginning in 1972 when a joint Solar Energy Panel of the National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA) recommended that wind energy should be developed to broaden the nation's energy options for new energy sources. In 1973, NSF was given the responsibility for the Federal Solar Energy Program, of which wind energy was a part. The Lewis Research Center, a Federal Laboratory controlled by NASA, was selected to manage the technology development and initial deployment of large wind turbines. Early in 1974, NASA was funded by NSF to (1) design, build, and operate a wind turbine for research purposes, designated the MOD-0, (2) initiate studies of wind turbines for utility application, and (3) undertake a program of supporting research and technology development for wind turbines. In 1975, the responsibility within the Federal government for wind turbine development was assigned to the newly created civilian research division – the Energy Research and Development Administration (ERDA) whose primary goal was to congregate all federal research and development in the energy area. (ERDA was later absorbed by the Department of Energy (DOE) in 1977).

A national wind energy program was launched to develop the technology necessary to enable wind energy systems to be cost competitive with conventional power generation systems and to be capable of rapid commercial expansion for producing significant quantities of electrical power. ERDA started recording all experiences with wind energy around the world and concluded that the most interesting experiences had been made in Germany and Denmark. In Denmark the attention was on Juul's construction of the Gedser wind turbine and after a visit to Denmark, ERDA paid Test Station Risø to rebuild the wind turbine, which had been down for nearly 10 years at that time, and measure the wind turbine's output under different wind and weather conditions.

The measures, however, did not result in anything visible as the leader of ERDA, Lou Divone, ignored them. Instead he set up a workshop with the German wind power expert Ulrich Hütter, the American engineer Palmer Putnam, and the former captain and professor William Heronemous, and when the federal government a few years later invested funds in research and development of modern wind turbines it had its eyes on the experiences and thoughts of these experts. Hütter and Putnam's ideas dominated the American high-tech approach to wind turbine technology for several years.

As a result, most of the funding was devoted to the development of multi-megawatt turbines, in the belief that U.S. utilities would not consider wind power to be a serious power source unless large, megawatt-scale "utility-scale" systems were available. The funds went to the development of high-tech wind turbines based on technology from large aircraft manufacturers such as Boeing, McDon-

nell Aircraft and Grumman. All in all, more than US$ 350 million was invested in huge advanced wind turbines after Hütter and Putnam's concept – a very aggressive and ambitious attempt to build a new industry that eventually would turn out to be a huge fiasco. (Jensen 2003)

NASA was in charge of the design work on a federal level and contracted General Electric's Space Division to design and build a horizontal axis wind turbine generator having a nominal rating of 1.8 megawatts (designated Mod-1.). (General Electric 1979) Managed by NASA and operated by BREMCO, the wind turbine was hoped to be part of a renewal energy movement begun under President Jimmy Carter. Unfortunately, the super advanced wind turbines were pure catastrophes. The turbines were burdened by a mistake in the design that took four years to fix. The NASA engineers using Hutter's two-bladed, downwind rotor idea for their early designs did not realize the importance of his "teetering hubs". It took several years of engineering studies to solve the problem and to switch to a configuration based on the design of Juul's more low-tech and solid construction. The costs were enormous. Because it was designed before the problems with the MOD-0 were understood, the design was a lame duck even before problems scuttled the first and only installation at Boone, North Carolina. (Dodge 2002)

Boone, North Carolina

The Federal Energy Research and Development Administration had begun its research into wind-powered energy in 1973 and the Department of Energy sorted through the nation's utility companies to find a suitable spot for this new breed of wind turbines; a research project which should determine if wind could be used effectively to generate electricity.

ERDA asked utilities across the nation to submit sites for future large wind generators. More than 70 utilities responded and in 1977 four areas were chosen to receive one of the wind turbines with the largest one capable of producing 2,000 kW. This – the world's greatest wind turbine and the granddaddy of them all – was awarded to Boone, North Carolina under the umbrella of Blue Ridge Electric. The Blue Ridge Electric Membership Corporation would operate the wind generator and the electricity generated would be fed into the Blue Ridge Electric distribution system.

The wind turbine was placed at Howard's Knob because of the wind quality there. The turbine, a $6.2 million, ten-story, 350-ton, 2000 kW (two million watts) monster, developed by the National Aeronautics and Space Administration and built by General Electric, had blades as long as the wingspan of a Boeing 747, and a control system automatically aligned the rotor with the wind. It was hoped that the wind turbine would generate enough electricity for 300 to 500 average size homes at winds of 25 mph and was an instant success – but not for long.

Standing 131 feet high, sporting two 97 foot blades that rotated counter clockwise at 35 miles an hour, the wind turbine generated much fanfare when it was announced that Howard's Knob had been chosen for the largest working model designed to convert wind power to electricity.

First of all, the residents around Howard's Knob complained about poor television reception and the gentle but consistent noise from the blades. DOE restricted operating hours to 8 a.m. to 5 p.m., which meant that the wind turbine lost strong evening winds. In addition to this, the big wind turbine was haunted by breakdowns and the reported $30 million total in upkeep for the short 300 hours of work the wind turbine provided simply did not warrant further waste.

Techniques used to reduce the annoyance included reducing the speed of rotation and replacing the steel blades with fiberglass blades. Other operational problems, including a broken low speed shaft, plus a reduction in federal funding, causing the once great wind turbine to be disassembled. This happened under much attention from the media and the public in 1982, only four years after it had been erected.

The wind turbine was hoped to be part of a renewal energy movement begun under President Jimmy Carter. However, interest in wind power as an alternative energy source declined and today nothing is left of the wind turbine at Howard's Knob. But the remains of what was once the hope of the American wind turbine industry can be seen today at a museum in Boone as a proof that this small town in North Carolina was once on the map of the American wind program.

Federal research on the MOD series of turbines was terminated in the mid 1980s, and all the turbines have been scraped. One reason was that smaller turbines (in the 100-kW range) could be built at lower costs and with better performance than the large turbines. Many of the involved underestimated the difficulty of building large reliable wind turbines. The technology step was just too large.

A second reason was that the American aerospace industry did not have a desire to produce a cost effective commercial product. Wind turbine research was viewed as just another government contract. A given company would build a turbine on a cost plus basis and when it broke, it would be repaired on a cost plus basis. But as soon as the federal money ran out, the company's interest in wind power vanished.

A third reason for the lack of interest in wind was the abundance and depressed costs of petroleum products throughout the 1980s and into the 1990s and the resulting sentiment that energy was no longer an issue. In the mid-1970s, it was standard wisdom that the country was running out of natural gas. Many utilities converted from burning natural gas as a boiler fuel, instead using coal or nuclear energy. The price of natural gas increased substantially from its artificially low values. But by the mid-1980s, it was discovered that we had substantial reserves of natural gas (at this higher price), and utilities started converting back to natural gas as a fuel, especially for peaking gas turbines. The development of wind power has certainly been delayed by these various actions of the government, aerospace, and oil industries. (Johnson 2001)

Researchers and Manufacturers

As opposed to the researchers in Denmark, the participants in the American research and development were highly competent, at least on paper. The government – in the form of the American Department of Energy and NASA – performed the main part of the research in cooperation with high-tech companies such as Boeing Engineering, Westinghouse, General Electric and McDonald Douglas who also "won" many of the earlier mentioned development contracts. (Karnøe & Jørgensen 1995)

The results were discouraging. The technology became too complicated and too expensive in the end and could not be sold in the commercial market. In spite of large budgets and professional staff from the industry, the strictly controlled development programs did not succeed in developing a viable commercial wind turbine concept. Wind turbines were manufactured and built and they did work and produce electricity but they still had many defects and operation problems making them far from cost-efficient.

A small machine development effort was belatedly started in 1976, when a federal test center established at Rocky Flats, Colorado found that available machines were neither properly sized, nor reliable enough, to do the jobs envisioned by federal application studies. Within four years, 13 wind turbine designs in five application-based size-ranges were procured, designed, fabricated, and tested. Successes of this program included 1-3kW and 6kW small turbines commercialised by Northern Power Systems and still being sold for remote power uses, and a three-bladed 40-60kW machine installed by the hundreds in California wind farms by Enertech. (Johnson 2001)

The first "real" NASA wind turbine was the 100-meter diameter MOD-2. Three of these machines operated for several years at a site overlooking the Columbia River in the 1980's, providing valuable engineering data and helping to pinpoint design weaknesses. Others operated at Solano, California and near Medicine Bow, Wyoming. The MOD-2 was an inevitably flawed experimental machine because of the huge technological leap it represented from the MOD-1. (Johnson 2001) But, in 1981, the biggest successes of the federal program were not measured in hardware, but in the number of designs shown to be unfeasible and in the amount of expertise developed in both the federal programs and in their private industry subcontractors. The ground had been laid for success (although this was not to happen).

The Carter and Reagan Administrations prematurely scuttled federal development efforts, when the banking and investment industry threw its lobbying support behind wind industry efforts to obtain huge energy tax credits. Due to these very favorable incentives there was no time for the "simpler is better" philosophy or developing reliable hardware from exploratory developments.

While the tax credits seemed to some to be an evolutionary development, they actually amounted to a complete redirection of U.S. energies. Administration officials were in charge of the planning of

this re-direction. They mistakenly thought that wind turbines were a mature technology that needed no further development and believed the over-optimistic claims of investment-hungry wind businesses that cost-effective and reliable designs were already available. (Johnson 2001) The tax credits were linked to the investment in wind turbines and not to the production of electricity.

In the 1970s there were nearly 50 domestic wind turbine manufacturers in the US although only 13 of these were of considerable size. The investment fever and the Californian boom in the early 1980's created large American wind turbine manufacturers such as Enertech and US Windpower, which both delivered thousands of wind turbines to California. None of the small wind turbine companies were, however, owned by large companies committed to long-term market development so when the sudden expiration of the tax incentives in the mid-1980s became a reality and the energy crisis eased of (both of which reduced market demand) most of the small wind turbine industry disappeared once again. Only the companies with reliable machines and a good reputation survived this period.

Since the 1970s, the wind industry has undergone massive consolidation, which was a result of the expiration of the tax incentives in the mid-1980s and the easing of the energy crisis, both of which reduced market demand. A competitive marketplace to weed out inferior products further contributed to consolidation. This resulted in less than a dozen domestic manufacturers in 1997. Roughly half of these deal exclusively with small-scale models leaving only Enertech and US Windpower as noteworthy manufacturers in the global marketplace.

At the turn of the century, however, the market for wind energy had grown so much that large traditional energy-companies such as Shell and General Electric started to show interest. Shell's subsidiary, Wind Energy, focuses, as the name indicates, on wind power only and has among other things bought two large wind farms in the US. General Electric's subsidiary, GE Power Systems, on the other hand, bought the wind turbine manufacturing from the scandalised energy conglomerate Enron in 2001. GE's return to the industry (the company was one of those given several millions for research and development in the 1970's) has been looked upon as some sort of indication of wind power being slowly overtaken by the huge energy corporations. However, only time can tell. But given the size of these companies the Danish manufacturers definitely seem to pale in comparison. (Jensen 2003)

The California Wind-Rush (Chance)

After 1980, the market in the United States – and especially California – was dominated by the emergence of "wind farms". This market was an almost totally unexpected phenomenon resulting from the coalescence of several application-dependent, legislative, and economic factors.

The market evolved thanks in part to a new Federal law under President Carter; the Public Utility Regulatory Policies Act of 1978 (PURPA), in which he forced the utilities to buy electricity from

private, non-utility individuals and developers at a substitution price. PURPA was specifically intended to create a market for clean, renewable, electric-generating technologies by guaranteeing a buyer for the excess power. Prior to PURPA, selling power to the utility was an option but was the discretion of the utility. At the same time President Carter also introduced a tax deduction of 15% on investments in alternative energy on top of the 10% deduction on general investments. (*Wind Energy Manual 2000*)

Situated on the West coast of the United States, California has a very windy climate and the availability of windy, sparsely populated mountain passes coupled with periods of high winds over the coastal hills correlate fairly well with high commercial and residential air conditioning loads in the summer. President Carter's initiatives inspired California's governor Jerry Brown. He and his employee Tyrone Cashman (a past president of the American Wind Energy Association and current president of the Solar Economy Institute), realized the potential in wind energy and set the goal that by year 2000, 10% of the state's energy supply should be supplied from wind energy. In order to achieve this the California administration introduced an additional tax deduction of 25%. (Dodge 2002)

Together with the federal energy credit of 15% and the 10% federal investment credit, this additional California state energy credit – combined with the traditional rules of depreciation – meant that 60-80% of the investment in a wind turbine could be financed through tax deductions. Coupled with the attractive rates offered by utilities for power produced by alternative sources (mandated by state regulations) an attractive investment product was created and the course for the California wind turbine boom had been set out. (Dodge 2002)

More than 50,000 Americans invested a total of more than US$ 2 billion in the development of wind energy in California. More than 17,000 machines, ranging in output from 20 to 350 kilowatts, were installed in wind farms between 1981 and 1990 and at the height of the development, these turbines had a collected rating of over 1,700 megawatts and produced over three million megawatt hours of electricity, enough to power a city of 300,000. (Dodge 2002)

The tax incentive was primarily directed towards erecting the wind turbines, which had to be done by the December 31st in order to redeem the tax credit. For many manufacturers it was tempting to not worry about protracted testing when customers were willing to buy almost anything with a tower, wings and a generator. Many, however, did not recognize the power of the Californian winds and the beginning of the Californian wind rush was characterized by split wings, overturned wind turbine towers, oil spill from leaking gearboxes and unscrupulous developers who left the state with technological and economical hangovers. (Jensen 2003) This gave the Danish manufacturers a chance to gain a foothold in the American market as their wind turbines, given the high quality standards set by test station *Risø*, were more than geared for strong winds and therefore much more reliable in operation than those of the American manufacturers.

Despite the speed with which this governmental program was initiated and began to show results, this program ultimately proved to be largely ineffective because of the interference of political factors and the withdrawal of financial support before success could be achieved. The popular tax incentives had proven to provide a very weak incitement in securing good and stable production of wind turbines, which in many cases never produced a single kWh.

In 1992 President George H.W. Bush cancelled the previous tax incentives and unveiled a set of federal Production Tax Credits or PTCs, which depended on the actual output from the wind turbine and gave wind-plant operators a 1.8 cents credit for each kilowatt-hour they sell. In addition to this the price guarantee agreement was withdrawn in 1995, resulting in decreasing prices based on market forces. Together with local incentives, this should bring the industry to new heights but the PTCs are not ideal, as they are only useful to companies such as utilities that earn steady income. But they're a step up from earlier investment-based credits, which gave wind producers little incentive to maintain wind facilities after taking the initial credit. The current PTC is set to expire at the end of 2003. Still, industry executives say that support for wind is greater now than on the past two occasions the credit was renewed. "The industry's at a point where it could probably get by without [the PTC]," says Edwin F. Feo, a lawyer specializing in energy finance at Milbank, Tweed, Hadley & McCloy LLP. (Aston 2003)

With continued government encouragement to accelerate its development, this increasingly competitive source of energy will, according to AWEA, provide at least six percent of the nation's electricity by 2020 and revitalize farms and rural communities – without consuming any natural resource or emitting any pollution or greenhouse gases. (*Wind Energy – an Untapped Resource*)

Related Industries

The suppliers can be divided into two categories: those who deliver standard components to both the wind turbine industry and to a number of other industries, meaning that the wind turbine manufacturers are not necessarily large customers. The other category of suppliers consists of those who deliver exclusively to wind turbine manufacturers. The issue of sourcing is particularly important in relation to this category of suppliers, who have to make rather specific investments in order to be capable of delivering highly specialized products. This is where the wind turbine manufacturers may reap particular benefits if they pursue a vertical integration strategy, which has clearly been the trend over the years. Just as in Denmark, most wind turbine producers have had a long tradition of close cooperation with a few suppliers of individual components but due to the fact that the manufacturers produce more and more components in-house the suppliers are increasingly being squeezed by the wind turbine industry.

The Public (Demand)

Numerous public opinion surveys have consistently shown that the public prefers wind and other renewable energy forms over conventional sources of generation. In the US, the public has been affected by the green movement and has shown great interest in wind energy – although it does not seem to have evolved into the consistent support seen in Denmark. This is illustrated by the fact that many investors in California were doctors and other professionals investing more in tax deductions and not in wind energy and an environmental belief as such.

Conclusion

It should be clear from the previous sections that the area of wind energy more or less from day one has been infected by politics. As a new source of energy with no market and a weakly described technology it would probably never have survived without the help and support of the governments and the public. There are many barriers to the successful development of wind energy, including prejudice, misinformation, and opposition from vested interests. When the right policies and supports are in place, however, the market takes off. The great challenge for the politicians, however, has been to identify the right balance between force and incitements.

The political instruments and development strategies, which were implemented in the US and Denmark respectively, has had a great impact on the situation on the world market today. At the turn of the century the Danish wind turbine industry was, measured by the share of the world market, technology and design, an industrial success. Americans still wonder why they, in spite of the combination of a huge federal development budget and a large group of the best engineers from the best aircraft industry in the world, still had to see them distanced by former manufacturers of farm machinery in tiny Denmark.

The background for the Danish dominance in the international market is not obvious as the country was neither the first nor the only to launch wind turbine technological development programs. But the difference in the two countries' approach to the technological development and the surrounding environments are good indicators of what led to the current situation.

In the US, the government launched a top-down technology oriented program, where the aim was to develop wind turbines through computer simulations from the aircraft industry in the pursuit of fast technological advances and radical innovations for building large wind turbines that were economically feasible. Governmental institutions and theoretical scientists therefore characterized the program and engineers, who, based on their research, financed development contracts to "promising" companies. Once the support from the government stopped, these companies who operated in other industries and had other core competencies, had no basic interest in wind turbines – leaving the data and information from failed projects almost worthless.

The strategy was backed by favorable tax incentives, which certainly pushed the industry forward, and created a huge demand, especially in California. But the incentives were purely financial and based on how many wind turbines were erected before the end of the year. It therefore did not encourage the manufacturers to develop wind turbines of high quality – a flaw which ended up losing the market to the Danish manufacturers.

In Denmark, the development followed the bottom-up market based strategy. The market for wind turbine electricity was created through a law giving the wind turbine owners the right to sell their electricity to a fixed and long run guaranteed price paid by all electricity consumers. This resulted in a wind turbine market focusing on cost efficient production of electricity and dropped the wind turbine producers into a process of gradual technological improvements to produce cost efficiently to actual existing markets. The development started with small and medium-sized wind turbines, built by engineers and skilled artisans who already possessed technological knowledge in the area and who gradually improved the technology. In Denmark this successful policy of evolutionary growth was supported by a clear political commitment to wind energy. The government established the policies that gave investors the price stability they needed, enabling the industry to take off and develop.

In addition to the political support, the success of the Danish wind turbine industry was achieved through tough internal competition between the wind turbine producers, knowledge sharing and learning effects. Other important factors in the development are the establishment of branch organizations and a strong industry association, test station *Risø*, active grass root movements and public support – all contributing to a supporting environment giving the industry the best possibilities for development.

Compared to the US model, the Danish approach was inspired by a few charismatic people who were widely supported by both the government and the public. The “Danish Turbine Concept” as it was developed by Juul in the 1950, was solidified by the 1970s energy movement and commercialised by the industry in the 1980s and in the end won out over all other competitive models and designs setting the standard for modern electricity-producing wind turbines.

The Future

The increasing reliability of wind turbines and the growing penetration of worldwide markets, means that the future for the technology is bright.

The emerging utilization of wind power from offshore wind turbines seems promising because of the more abundant wind energy at seaside. A major technological break-through for offshore wind turbine technology might initiate a new wave of product and process innovations and if this is the case, the prophecy of an imminent mature phase for the wind industry has been delivered too early.

The question then becomes – who will win this next race? Will the U.S. learn from its previous mistakes and can Denmark continue its – until now – dazzling industrial development and defend its position as the global market leader? A continued growth in the wind turbine industry driven by demand and increased cost effectiveness certainly will attract new big players into the market and drastically change the rules from a game where technology and production ability are the most important factors to a game where access to capital and market power becomes more important

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