CREATING A LOCAL WIND INDUSTRY

Experience from Four European Countries

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Author's Note

The following paper is strictly attributable to the author, and does not necessarily reflect the views or positions of the Danish Wind Turbine Manufacturers Association.

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TABLE OF CONTENTS

INTRODUCTION

Several countries in the world are looking with increasing interest at wind energy, both for its use in an environmentally sustainable electricity supply, and for its potential to create new economic activity.

Today, wind prospecting, research and development, turbine manufacturing, and installation employs more than 35,000 people worldwide, and the industry has become a 1.5 billion (USD) dollar world industry. [41] The growth rate of the Danish and German part of the industry within the past 5 years even exceed the growth rate of Nokia, Europe's largest mobile phone manufacturer, or the number of servers on the Internet. [42]

This report consist of five papers: This general paper about employment, industry, markets and technology, plus four country studies of energy policies, support mechanisms, markets, and industry.

CHAPTER ONE

THE WIND TURBINE MARKET IN DENMARK

1. Wind Resources

Denmark has relatively modest to good average wind speeds in the range of 4.5 to 5.3 m/s measured at 10 m height, equivalent to typically 6.5 m/s at a wind turbine hub height of 50 m. (The highest average wind speed at hub height onshore is about 7.5 m/s). Onshore wind resources are highest in the Western part of the country, and on the Eastern islands with coastlines facing South or West. [1]

The country has very large offshore wind resources and large areas of sea territory (and economic zones) with a shallow water depth of 5 to 15 m, where siting is most feasible. These sites offer higher wind speeds, in the range of roughly 8.5 to 9 m/s at 50 m height. [2]

2. Wind Generation Structure

Wind development in Denmark is spread geographically throughout the country, although with higher concentration in the windiest areas noted above. [3] Single wind turbines or, increasingly, clusters of turbines are the most common siting method. There are comparatively few large wind parks. The reason for this is partly the planning policy preferences (generally against large parks, and favouring clusters), [4] and the Danish ownership restrictions which effectively (though not intentionally) encourage single turbine siting. [5] 80 per cent of Danish wind power capacity is owned by individuals or wind co-operatives. The rest is owned by power companies. [6]

3. Renewable Energy Policy for Wind

Denmark, which in the early 1970s was extremely dependent on (imported) oil, pursued a very active policy of energy savings, increasing self sufficiency, and diversification of energy sources until the mid 1980s. Since then, energy policy has increasingly promoted the use of renewable energy to ensure environmentally sustainable economic development. [7]

Long term planning is considered to be important, with a planning horizon presently set at the year 2030 in the Government policy document "Energy 21". [8] 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, plant and equipment have long lifetimes (e.g. transformers, transmission systems and generating plant). One important aspect of present planning is to ensure that the future electricity system will be able to accommodate a very large share of intermittent renewables.

Since the mid 1980s, the country has had an official goal of meeting 10 per cent of Danish electricity consumption by wind in the year 2005, implying an installed base of 1,500 MW of installed wind capacity. [9] It now seems likely that the target will be reached by the year 2000, and new ambitious Government plans in the "Energy 21" policy document indicate that around 50 per cent of electricity consumption should be covered by wind by 2030, most new installations being located offshore.

4. The Energy Policy Role of Power Companies

The Danish Government has very wide-ranging powers to regulate utilities. Regulation takes many forms, including energy efficiency and demand-side management (DSM) measures. Integrated Resource Planning (IRP) is an integral part of the procedure through which power companies obtain permission to install new generating capacity. Other measures include price and accountancy controls[1].

The Government has ordered the utilities to install 400 MW of wind power on land to date. The first two orders of 100 MW 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.[2] In 1998 a new order was issued for 750 MW of offshore wind power.

[1] Permissions to install new capacity are subject to strict environmental criteria. E.g. coal has been outlawed as a fuel for new generating facilities. Danish power companies (mostly co-operatives) are tax exempt, provided their annual accounts show no profits. Accountancy rules, however, provide generous depreciation allowances, which allow power companies to depreciate 75% of the cost of new plant 5 years prior to investment. [10] This effectively allows power companies to collect funds for investment from electricity consumers before investments are made. [11]

[2] This is, of course, in addition to the existing and future cooperatively- and privately-owned turbines, which account for the majority of wind generation in Denmark.

Wind turbine orders from power companies are filled by competitive public tendering. Formerly the tenders were based on power companies doing an extensive part of site prospecting, installation, and servicing work. Lately, turnkey contracts with manufacturers have become the rule, since they are expected to be significantly less expensive for the power companies.

The use of turnkey tendering makes the process more similar to the NFFO or SRO system used in the UK than what is generally realised.

5. **Power Companies' Ownership of Wind Power**

Danish utilities are mostly non-profit co-operatives owned by the electricity consumers in each area, although some municipalities in the larger cities are the owners of distribution companies. Ownership of distribution companies cannot be traded, but is implicitly held by the property owners who consume electricity. Governing boards are elected locally. The distribution companies jointly own transmission and generating companies.

The many local power companies operate an internal sharing arrangement for their wind energy deployment, which means that they effectively pool their wind energy investments to ensure that wind energy is deployed primarily in good, windy areas.

6. **Attitudes to Wind Energy in Power Companies**

Danish development of wind power could probably have been carried through with private (non-power company) investment only, like in Germany. The primary advantage of power company participation from a political point of view has been to ensure that expertise and renewable energy commitment within power companies has been much larger than what would otherwise have been the case. Until recently, however, there was a dividing line between an overall positive attitude at the technical level, dealing with practical wind power implementation, and a more reserved attitude at the political level of utility boards, basically resenting cost and tariff increases due to (costlier) renewables.

The improving economics of wind energy has changed this: Power companies today realise that wind is the cheapest option for meeting the (legal) environmental requirements for power companies, the objectives of which are likely to remain on the political agenda for the foreseeable future.[3] In this situation, the power companies have urged that the Government leave wind development to power companies only, since with the present energy tax refund system, it is 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 around 0.28 - 0.34 DKK/kWh (0.04 USD/kWh). But since they get a CO2 tax refund of 0.10 DKK/kWh, their generating cost is really 0.18 0.24 DKK/kWh. versus 0.30 to 0.37 DKK/kWh (0.05 USD/kWh) for energy purchased from independents. [11]

It should be realised however, that these power company costs are quoted on the basis of a 5 to 6 per cent real rate of interest, and a 20 year project lifetime, and that the costs do not include grid reinforcement. It should also be noted, that Danish infrastructure is characterised by a strong electrical grid, and widespread local expertise in installation and planning. The extensive 20-year experience with wind energy is indeed reflected in lower installation costs than elsewhere in Europe. [12]

The strengthened commitment of Danish power companies to wind energy can be seen in their eagerness to develop the first 750 MW of offshore wind power, where applications for planning permission were launched even before the actual Government order was issued.

7. **Public Service Obligations**

The European Union directive on the liberalisation of electricity markets allow member countries to impose a "public service obligation" (PSO) on electricity suppliers, which are allowed to shift the cost burden onto consumers. The obligations may, for example, be related to ensuring universal service to all consumers in a region at the same tariff , meeting obligations in relation to environmental policy, or funding research.

In regard to renewables, the Danish legislation ensures that all electricity consumers effectively have to share the excess cost, if any, of using renewables in the electricity system, in order to avoid distortion of competition between suppliers. In practice this means that electricity generated using renewables, or all forms of combined heat and power production (CHP) has a priority access to the

[3] Cf. Numerous press statement from the President of the ELSAM Utility Group, Egon Søgaard.

grid.[4]

8. **Municipal Planning**

The policy of installing 1,500 MW onshore in Denmark has been considered a challenge for municipal and regional planning, given the country=s high population density[5]. For the past few years Danish municipalities have been required by a planning directive from the national Government to make plans for wind turbine siting. [13]

Although no specific quotas were set by the national Government, most regions (counties) have required municipalities with good wind resources to provide suitable sites for turbines. After the recent round of planning with extensive hearing procedures for local residents, sites for more than 2,600 MW have been made available. [14]

The Danish system has inspired a similar system, which is being implemented in Northern Germany. [15]

9. **Advanced Wind Resource Mapping**

To assist municipalities carrying out planning for wind turbines, a national wind map based on rough manually prepared estimates was made available in 1991. [16]

A new and much more advanced method is being employed in 1997-98: Using the European Wind Atlas Method (WAsP) developed by Risø National Laboratory, software from the leading commercial wind software vendor Energy & Environmental Data, and detailed digital maps, a very

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[4] It is up to utilities to implement a tariff structure which implements this. In the estern part of the coutry, the transmission company ELTRA has implemented this using a tariff which reflects the energy mix during each period. In winter, when there is a lot of CHP-generated electricity and much wind, tariffs tend to be slightly higher than in summer. Large customers who have the right to purchase electricity from any generator in Europe effectively have to buy a mixture of locally made prioritised electricity and imported electricity (plus transmission fees). [12]

[5] It is in fact a testament to wind power=s general acceptability that it has developed so powerfully in densely populated countries like Denmark, Germany and the Netherlands (the second most densely populated country in the world, after Bangladesh).

detailed, automated analysis of the entire country (divided into cells of 100 by 100 metres, with automatic assessments of terrain roughness out to 20 km distance) is being prepared.

The system already includes an exact mapping of all 4,800 wind turbines in the country, and the results will be calibrated by production data from more than 1,500 wind turbines reporting to the monthly statistics system run by the software vendor for the Danish Wind Turbine Owners' Association.

10. Market Development Schemes

In the beginning of the 1980s the Danish Government instituted a number of successive market development schemes, originally funding 30 per cent of investments in new wind turbines, but gradually lowering this support until it was abandoned in 1989 (it was 10 per cent by then). [17]

11. Pricing of Wind Energy from Independent Power Producers

Power companies are by law required to pay for electricity from privately owned wind turbines at the rate of 85 per cent of the local, average retail price for a household with a (high) annual consumption of 20,000 kWh (effectively allowing a gross 17.6% markup on sales of electricity from this source). [5] (The reason for the 20,000 kWh rule is that electricity prices in most areas include rental fees for meters, but the tariff structure varies with the local distribution company).

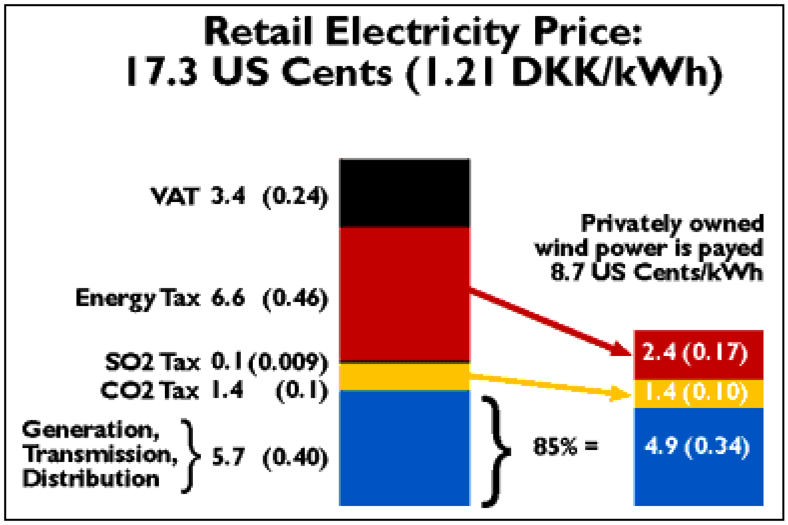
The electricity price paid by power companies for wind energy from privately owned wind turbines varies between 0.25 and 0.35 DKK/kWh (0.036 to 0.05 USD/kWh), reflecting the varying prices of electricity from different local distribution companies.

The price is not substantially different from what would have been obtained under the time tariff system applied to other independent power producers. Under that system the generator is paid different rates, depending on whether deliveries are made during peak, medium load or low load hours. Since wind energy production in Northern Europe tends to be highly correlated with demand (more wind at day than at night, much more wind in winter than in summer), wind is actually some 40 per cent more valuable in the grid, than if production were purely random. [19]

Originally the pricing arrangement was negotiated between the Danish Wind Turbine Owners' Association and the Association of Danish Power Companies. In 1992 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 made a general law on renewable energy, including a purchasing obligation with the tariff mentioned above.[6]

12. **Partial Refund of CO_2 and Energy Tax**

Households in Denmark pay very high electricity prices, even though Denmark has some of Europe's lowest generating costs for thermal plant. The reason is an extremely high indirect taxation of electricity, as shown in the graph above. [20] The political reasoning behind the high taxation is to reduce pollution emissions and encourage energy savings. (The fiscal motive plays a role as well, of course: "Green" taxes are less resented by voters than other taxes).



The electricity tax is collected on all electricity sold to households, service businesses etc. Only manufacturing industry is to a certain extent exempt from this taxation.[7]

Electricity from renewable sources gets a refund of the 0.10 DKK/kWh (0.014 USD/kWh) CO_2-tax [5]. This refund is paid regardless of whether the generating equipment is owned by power companies, firms or households. This particular tax is called the CO_2 tax. (The labelling of different electricity taxes is historically somewhat random, depending on whether the originally declared political aim was environmental or fiscal).

[6] The events are descibed in detail in an article by the Danish Wind Turbine Owners= Association, Flemming Tranæs, posted at the internet address http://www.windpower.dk/articles.

[7] Under very complex rules which graduate the tax according to the use of the energy. Heating is taxed like household use, while process use is taxed very lightly. Companies which embark on particular energy savings programmes may be partially exempted from the tax.

13. **Special Rules for Private (Individual or Co-operative) Owners**

Wind turbines owned by non-power companies, i.e. other firms, individuals or co-operatives, in addition get a refund of 0.17 DKK/kWh (0.024 USD/kWh) of electricity tax. [5] The size of the refund has been set to ensure a reasonable profit for wind turbine owners, given existing tax regulations. On the other hand, there is currently some political concern that the profitability of wind energy is "too high" on the very best sites. [21] Some future adjustment, primarily concerning these sites cannot be excluded.

Total remuneration for private (non-power company) wind turbine owners varies between some 0.5 and 0.62 DKK/kWh (0.071 to 0.089 USD/kWh).

The basic reason for treating power companies and other turbine owners differently is that power companies in Denmark are tax free, provided that they do not make a profit. (Generous accounting rules allow power companies advance depreciation, which effectively ensures, that they are tax free, "non profit" institutions. They are allowed to collect investment financing in their tariffs, before investments are actually made, thus obviating the need for shareholders or other external sources of finance).

14. **Grid Connection, Grid Reinforcement**

According to the Executive Order on Grid Connection of Wind Turbines of 1996 [5], local power distribution companies are obliged to provide grid connection facilities at any site which in municipal planning has been set aside for the development of at least 1.5 MW of wind power (rated generator power).

In other cases, power companies are obliged to allow grid access to the local 11-20 kV grid, but the turbine owner is responsible for paying for the extension of the grid to reach the site in question. The power company has to pay for the entire grid extension, however, if the cabling can be used for other purposes in the normal extension of its grid facilities.

The necessary reinforcement of the grid is paid for by the power company, unless the power company can prove that the reinforcement in the area is particularly uneconomic. The Danish Energy Agency (part of the Ministry of Energy and the Environment) is the authority to whom prospective turbine owners may appeal power company decisions on these matters.

Wind turbine owners have to pay for the transformer to connect to the 11 kV grid. In addition a fee for rental of electricity meters apply. (Reactive power consumption is not charged, but turbines generally have to observe a certain phase angle [27]).

15. **Tax Treatment of Wind Turbine Investments**

Wind turbines are treated like machinery in industry, i.e. a declining balance 30% annual depreciation is allowed.

Wind turbine owners may alternatively (once and forever) opt for a simplified tax system, being taxed on 60% of gross revenues from electricity sales exceeding 3,000 DKK/year (450 USD/year) without any depreciation allowance or any deduction of other costs. This means that people who only own a few shares in a wind turbine co-operative are not taxed on their wind turbine income.

16. **Limitation on Private Ownership**

The private (non-power company) ownership of wind turbines in Denmark is limited by regulations in the executive order on national grid connection rules, requiring that members of wind co-operatives be resident in the municipality where the wind turbine is located, or in a neighbouring municipality. [5] Municipalities make exceptions for individual wind turbine projects, but exceptions are fairly rare.

The regulation also limits the number of shares residents may own in a wind turbine co-operative to an annual production of 30,000 kWh per (adult) person, corresponding to a total investment of some 120,000 DKK (17,000 USD).

These restrictions were allegedly made "to prevent the misuse of Government support schemes for wind energy" (quote from the Minister for Energy and the Environment in Parliament), but the basic political aims are probably to preserve local ownership of the exploitation of a natural resource, much like it is practised in Danish agricultural legislation which requires that farm owners be resident on their farm.

Individuals may own one wind turbine located on the same property on which they are resident (no size limit). The ownership of a complete wind turbine and co-operative shares are mutually exclusive.

The quantitative restrictions on independent power production were likely imposed as a result of visibly strong political pressure from power companies.[8]

17. Market Size

The total installed base of wind power was some 1,100 MW at the end of 1997, making Denmark the third largest wind power country in the world after Germany and the USA. Almost 300 MW were installed in 1997, making it another record year for installation of wind power (with 200 MW and 98 MW in the two previous years).

18. Turbine and Component Suppliers

All of Denmark's 4,800 wind turbines (end 1997) have been manufactured domestically. Denmark hosts five of the world's ten largest wind turbine suppliers: NEG-Micon, Vestas Wind Systems, Bonus Energy, Nordex, and Wind World. The first three companies account for more than 50 per cent of world production of wind turbines measured in MW. Most of these companies have a background in agricultural machinery manufacturing, with the exception of Wind World which was founded on gearbox and marine technology manufacturing.

Competition in the Danish market is definitely the toughest in the world, making the market rather uninteresting to foreign turbine suppliers. Another problem facing some foreign suppliers may be the very stringent safety regulations which e.g. require two independent failsafe braking systems on turbines, one of which must be aerodynamic, or providing equivalent safety.

The Danish component industry includes LM Glasfiber, which is the world's largest rotor blade manufacturer, with an employment of more than 1,000. Danish manufacturers of electronic wind turbine controllers likewise have a very large market share world wide. Other component

[8] It is somewhat doubtful whether these regulations are in accordance with EU rules on the free movement of capital, since they effectively prevent cross-border ownership.

manufacturers include suppliers of braking systems, hydraulics, etc.

19. Employment

Denmark is home to 60 per cent of the world's wind turbine manufacturing capacity. Presently about 2/3 of production is exported. The Danish wind turbine manufacturers presently employ some 2,200 persons, in Denmark, while domestic component and service suppliers employ another 10,000 people (1997).[9]

In addition, another 4,000 - 5,000 jobs are created abroad through deliveries of components, and installation of Danish turbines. These figures do not include assembly work etc. done in foreign subsidiaries or licensees of Danish firms.

20. The Home Market's Role in Industry Development

The Danish home market is what created the modern Danish wind industry originally, and gave it the testing ground to sort out both wind technology and manufacturing technology, including the important issue of quality control.

When the Great California Wind Rush started in the early 1980s, the Danish companies were practically the only ones in the world with a substantial track record. The result was that investors tended to prefer Danish machines, which in the end made up around half of the capacity installed in California. The importance of the learning process within the major Danish manufacturing companies from manufacturing thousands of machines for the California market cannot be overestimated.

21. The Danish Concept

[9] These figures are a cautious estimate updating an extensive input-output analysis study conducted in 1995 by the Danish Wind Turbine Manufacturers Association. [18]

The track record of the early Danish machines in California has in general been better than those of the competitors, leading to yet another track record advantage. The result is, that the so called "Danish Concept" in its newer and more refined versions today dominates the international wind turbine market more than ever, despite occasional revolutionary technology predictionsin the press.

The last company manufacturing vertical axis machines (Flowind) went bankrupt in 1998, and manufacturers who used to stick firmly to a two bladed concept (WEG, Nedwind and Lagerwey) have all launched new three bladed designs.

As matters stand at the time of writing, it appears that the "Danish Concept" consisting of a three bladed upwind design with fixed speed operation and direct grid connection rules about 75 to 80% of the market. [23] This design dominance resembles the status of the 4-stroke petrol engine which has actually been around since 1856.

Whether other designs (full variable speed operation, indirect grid connection) will penetrate the market is largely a matter of component costs, in particular the costs of power electronics. There is, of course, a bit of circularity in this argument: Costs will decline with large scale manufacturing, so nothing is given about future technology in this area. It seems likely however, that the present basic design will dominate the market well into the next century.

22. Can the Danish Industrial Success be Replicated?

The Danish success in wind energy is not easy to replicate elsewhere, and certainly not with the same means. Technology development is different today, markets and competition are different, and in some sense the Danes were fortunate enough to be in the right place at the right time with the right concept.

Starting from scratch is much more difficult today, when the largest market segments have tougher competition, with a more mature and reliable technology. The same market segment requires large machines with larger capital requirement and higher development risks.[10] Furthermore, there currently are no fundamentally revolutionary turbine technology concepts in sight, i.e. demonstrably

[10] The technological innovation process and different design strategies in the wind turbine industry are thoroughly analysed in [22]. A summary of the major design options can be found on the web site of the Danish Wind Turbine Manufacturers Association, http//:www.windpower.dk/tour/design

economically superior technologies, although there are many options for further development and cost cutting within the major variants of present technology. [24]

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, and developed local manufacturing. Most of the licensees have a machinery and equipment manufacturing background. The primary advantages of a technology link to an existing manufacturer is to acquire proven technology, and the possibility of being able to offer a more complete and continuously optimised model range.

23. **Origin and Mainstay of the Market: Private Citizens**

Denmark is somewhat unique among wind turbine markets, since the market really grew out of a popular interest in alternative generating technologies, partly in opposition to the use of nuclear power, partly as a result of the energy supply crisis in the late 1970s, when oil prices skyrocketed due to OPEC action and political and military unrest in the Middle East.

Private individuals, either as members of wind energy co-operatives, or as whole owners of a wind turbine (farmers) account for about 80 per cent of installed wind power capacity in Denmark. (Almost 900 out of 1100 MW of installed wind power capacity at the end of 1997). 100,000 families in Denmark own shares in a local wind turbine, and almost 2,000 wind turbines are owned by individuals.

Wind co-operatives are organised as unlimited partnerships, but since the turbine and its installation is usually completely paid up, partnerships have no loans and no (joint) risk in this respect.

24. **The Benefits of Thorough Statistical Coverage**

Wind turbine owners are highly organised in the Danish Wind Turbine Owners' Association which publishes a monthly magazine giving production figures and notes on technical failures for more than 1,500 turbines. This excellent statistical data base, plus user groups, and technical consultancy services for members has been a very important instrument to ensure a transparent market with tough competition between manufacturers.

Turbines are usually sold with 5 years guaranteed production (insured with insurance companies). This makes all manufacturers keen on not overstating expected production, as this would bounce back in the form of a higher risk premium for that particular brand from insurance companies.

25. **The Role of Publicly Financed R&D**

In stark contrast to Germany, Sweden, the USA, 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. [25] The early stimulus came in the form of investment grants, supporting market development for small scale privately owned turbines, (5 to 11 kW) which typically covered their owner's annual electricity consumption, by a factor of 2 to 4.

Later, the Danish Government and the European Union have financed a significant number of basic research projects, and given some support to development projects. It is estimated that a staff of about 60-80 people in Denmark (including both researchers and administrative staff) work on (partly) publicly financed R&D. Danish wind turbine manufacturers have a staff of about 100 people working on technology development. Total public support for this work is below 2 million USD/year.

26. **Type Approval Requirements**

In the late 1970s Risø National laboratory (whose original task was nuclear research) was charged with type approval of wind turbines which could be installed with public investment grants. The type approval process was extremely useful for weeding out low quality and potentially dangerous products, and put a pressure on manufacturers to upgrade their design and manufacturing skills. [22, 25]

Risø's very strict safety requirements, its demands for physical testing of rotor blades, and conservative norms for load calculations, indirectly saved the core Danish manufacturers from the fate of many foreign competitors whose turbines collapsed in these early days. The result was very sturdy and stable, but rather heavy machines. (The potential for weight saving has in fact been so large, that Danish wind turbines have shed half their weight per kW power installed during the past 5-10 years, despite a 50 per cent growth in their physical size).

27. The Role of Risø National Laboratory and Others

Risø has since the early eighties evolved to become probably the foremost international research institute on basic research in wind turbine technology and wind resource assessment.

A much smaller, complementary Institute of Fluid Dynamics developed at the Danish Technical University. Its parallel development of turbine design software has served as a commercial tool in many companies, and as an important tool to ensure mutual verification of its own and Risø's methods of aeroelastic analysis.

28. The Role of Power Companies in R&D

Danish power companies played a pioneering role in the early technology development of wind energy. When the Danish Government instituted a publicly financed wind energy research programme in the mid 1970s, the power companies once again became involved in wind power research, concentrating on relatively large machines for their time (630 kW), and building two experimental wind turbines near the town of Nibe around 1979 (one pitch, one stall controlled). These machines were finally closed down in 1997. In the early 1980s another group of five 750 kW machines were built, and during the 1990s another two experimental machines of 1 and 2 MW were built.

The primary aim of these ventures appeared to be the training and development of in-house wind energy expertise in the power companies, rather than aiming at commercially relevant equipment.

29. Is the Danish Market System an Economic Success?

The Danish market system for wind energy has been a popular success, in regard to the public's possibility of direct involvement in energy policy.

The power company share of the market (determined by Government orders to power companies) has worked reasonably well, except for the fact that power companies have been threeyears behind schedule in fulfilling their obligations (with no consequences for them)[11].

The refund of 0.10 DKK/kWh (0.014 USD/kWh) for power companies has apparently been based mostly on political considerations of the name "CO_2 levy" which was a convenient amount to refund. Since then SO2 taxes have been implemented without any talk of a similar refund to wind. Today the 0.10 DKK/kWh roughly compensates for the difference in average generating costs between wind and fossil fuel plant.

30. **Rationing Gives Questionable Market Efficiency**

The Danish wind energy support system has lately come under political attack for being too generous to private wind turbine owners, and conversely unnecessarily expensive in terms of energy tax refunds. The attack has been justified by reference to the capital gains (land rents) for windy sites.

The timing of the attack is directly related to the discovery of the regulatory loophole described above, which created a record boom in turbine investment in Denmark. (The boom was reinforced by the fact that the authorities by accident warned about a change in regulations beforehand, thus creating a virtual "buying panic before closing time").

This has been a clear demonstration of the fact that the "segregation policy" which had effectively excluded anyone but farmers from owning their own wind turbine, had the effect of keeping less risk averse (and more bankable) investors out of the market, and of keeping yield

[11]The first two orders to power companies were not legally executive orders, but the power companies "volunteered" to put up two times 100 MW, and entered into an agreement with the Ministry of Energy without a penalty clause, thus avoiding a legally enforceable executive order. The power companies say that difficulties in obtaining planning permission was the reason for their late compliance. The present 200 MW order and the 750 MW offshore order are in fact executive orders, but are referred to as agreements in power company publications. The reason for using executive orders (other than the enforcement aspect) is the EU directive on the free electricity market, where it is important that the utilities have the legal right to consider excess costs of renewables as a "Public Servce Obligation", whose cost may be included in electricity tariffs.

requirements (on the windiest sites) higher than necessary.

Likewise, the apparently acceptable price differential between negotiable shares in wind co-operatives and non-negotiable shares gives an indication of the liquidity premium paid for the "localness" of wind turbine ownership.

CHAPTER TWO

THE WIND TURBINE MARKET IN GERMANY

31. Wind Resources

Germany generally has modest average wind speeds around 4 m/s at 10 m height, but a few areas with good wind speeds in the coastal regions of Northern Germany in Schleswig-Holstein, and part of Niedersachsen. Inland, however, it is only possible to find good locations for wind turbines in areas with hilly terrain, where one can rely on speed-up effects. An important offshore resource may be found along the short North Sea Coast, and along the Baltic coast. [1]

32. The Role of Government: Market Development Schemes

Both the Federal Government and the individual states (Länder) have operated support schemes for the investment in wind turbines. The most important stimulus on the federal level came from the 250 MW programme. This was a national support programme introduced in 1990, originally with a 100 MW target. In March 1991, after the first year of the existence of the programme, the original target was exceeded, and therefore the programme was extended to 250 MW. [26]

The highly successful feature of this Government wind energy programme was an additional 0.06 DEM/kWh (0.034 USD/kWh) on top of the payments from power companies, according to the Electricity Feed Law (Stromeinspeisungsgesetz), see below. This helped to kick-start the market until it expired at the end of 1995.

Some additional 60 wind energy projects had been supported by a follow-up investment grant programme from the Federal Ministry of Economic Affairs between 1994 and 1997. Apart from the Federal support programmes for wind energy, several German Länder (states) introduced, during the 1990s, their own support schemes. Most of these support schemes have been phased out in later years, and the remaining systems are almost symbolic.

33. **Good Statistical Reporting Increases Transparency**

An interesting and useful feature of the German market development support schemes has been the requirement under the 100/250 MW Programme to report production, technical reliability etc. closely for the supported turbines. This has led to an interesting set of annual statistics published by ISET[12.] The reports are concerened with machine relaiability, causes and effects of failures, plus verification of wind climate assessments and power curves. Another statistical data base reporting on the production of wind turbines, comprising more than half of all operating wind turbines, is managed by the independent engineer's office IWET. In many ways this data base resembles the system operated by the Danish Wind Turbine Owners' Association, and it has been a good way of increasing market transparency. [15]

Like Denmark, Germany has a very strong free trade tradition, and its carefully planned support system did not (and does not) discriminate in favour of domestic suppliers. Its market development programme, however, has been well coordinated with its R&D support programme, and its subsequent Eldorado export promotion programme to support developing countries, and has created a viable industry, as explained later. Under the Eldorado programme, some 22 million USD had been spent for wind energy between 1991 and 1997. [15]

34. **Energy Policy for Wind**

Contrary to the Danish long-term policy approach, there has been no coherent official German policy for renewable energies. The main reasoning for a pro-active approach on renewable energy is Germany's strong commitment tocut carbon dioxide emissions by 25 per cent between 1990 and 2005. Speaking on the importance of the Stromeinspeisungsgesetz, the German Ministry of Economic Affairs writes: "An official bonus may be granted to environmentally friendly energy sources. This is possible ... by introducing a legal obligation whereby electricity generated from renewable energy must be purchased by the utilities at a fixed price, which is higher than the costs incurred by the purchasing utilities."[13]

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[12] Institut für Solare Energiversorgungstechnik, Verein and der Universität Gesamthochschule Kassel e.V.

[13] The German Ministry of Economic Affairs (Bundesministerium für Wirtschaft) is know as the first and foremost

35. **Pricing of Wind Energy: The Electricity Feed Law (Stromeinspeisungsgesetz)**

The Electricity Feed Law from 1991 requires German power companies to pay 90 per cent of the average retail electricity price for final consumers (household, commercial, industrial) (ex. tax) for wind (or solar) generated electricity supplied to the grid. [26][14]

Since electricity prices in Germany are very high[15], electricity tariffs for wind energy are quite high. These tariffs are sufficient to ensure profitability of wind energy on a good site in the coastal regions, and increasingly even with the moderate wind speeds prevailing in the inland areas. However, most turbines in the inland areas need some additional financial support due to the low wind speeds.

36. **Grid Connection, Grid Reinforcement**

Contrary to the Danish regulations, turbine owners in Germany have to pay for any costs incurred by grid reinforcement or extension caused by wind power. These costs can be quite substantial, especially in the rural areas of Northern Germany with a comparably better wind regime than inland. Due to the lack of legislation for grid reinforcement and grid extension costs, as in Denmark, and due to the low transparency of the German utilities in regard to transmission and distribution costs, many projected wind farms in northern Germany have problems getting started.

37. **Tax Treatment of Wind Turbine Investments**

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bastion of free market and free trade thinking in Europe. This quote is politically remarkable in the sense that it justifies tinkering with the market mechanism. Germany, like Denmark, has in principle favoured a universal European Union wide energy/CO_2 tax.

[14] The remuneration rate is lower, between 65 and 80 per cent, for other renewable technologies, including small hydro, landfill gas, sewage gas and various biomass sources and technologies.

[15] This is mainly due to the monopolistic structure of the electricity industry for more than half a century, although also to an historical preference for domestically mined coal for power generation. [15]

Wind turbines are treated like any other investment in Germany, including higher depreciation allowances in the initial years. General (non-wind-specific) incentives for investments in Eastern Germany apply until the end of 1998.

38. Favourable Financing Schemes

Agricultural financing institutes which offer low interest loans for agricultural investment may frequently be able to finance 90% of a farmers' wind turbine investment.

German investors are offered several favourable loan facilities to attract capital for wind power and other renewable energy projects.

The Deutsche Ausgleichsbank (DtA) is a federal institution under public law with the majority of its shares owned by the European Recovery Programme (originally the “Marshall”) Fund (EPR). The DtA/EPR Fund has granted low-interest loans to small and medium-sized companies since 1990 for installations using renewable energy. The average lowering of the interest rate on these loans is between one and two percentage points. Furthermore, interest rates are fixed for the entire duration of the loan which may be up to 20 years (but usually does not exceed 12 years). A maximum grace period of five years can be agreed in order to protect the liquidity of the investor, particularly during the early phase of the development. This instrument has proven especially effective to ease investments in wind power. The loan approvals, for all renewable energy, amounted to more than 2.2 billion USD between 1990 and mid-1997. Within five years (1990-1995), more than 1500 wind energy projects had been granted ERP loans totalling more than 500 million USD in conjunction with complementary DtA loans totalling some additional 300 million USD. [15]

About 80 per cent of all existing wind turbines have been supported by DtA's environmental protection loans.

39. German Power Companies' Attitude to Wind Energy

German power companies resent the obligation to give what they consider is an excessive price for electricity from renewables. The large, super-regional electricity company Preussen Elektra, in particular, has been complaining about uneven burden sharing, and alleging that environmental policy is not part of the obligations for German power companies in their monopoly charters which were granted by the Third Reich. However, the reformed German electricity law puts an end to the closed monopoly charters and clearly expresses in its preamble that environmental protection is one of the three pillars of German electricity suppliers.

The German Electricity Feed Law (Stromeinspeisungsgesetz) does provide a "hardship clause" which allows local distribution companies faced with large cost increases to shift the excess cost of their power purchasing obligation to the regional power company.

However, this option has never been used by the local or regional companies. An amendment of the law, coming into force probably in spring 1998, puts this hardship clause into more concrete terms, at the same time indirectly introducing a cap to the further expansion of renewable energy in the electricity sector. The obligation for utilities to pay the tariff set out in the Electricty Feed Law has been limited to only 5 % of their total electricity supply mix. This effective cap on wind energy is designed to protect regional utilities in windy areas against excessive financial burden. Once the volume of renewables exceeds 5 % of such a utility's sales, it can pass the exceeding amounts to the supra-regional utility, e.g. Preussen Elektra[16]. Once the supra-regional utility has reached the 5 % limit, additional renewable energy power would no longer receive premium payments. The super-regional power company, has no way of shifting its obligation to other regional companies.

In sum, utility companies in Germany are obliged by law to pay for renewable energy up to a maximum of 5% of total German energy consumption.

Since 1994 German power companies under the leadership of Preussen Elektra have mounted a joint attack on their power purchasing obligation through both the German Constitutional Court, and through a complaint to the European Commission about unfair competition. Both initiatives failed, and a subsequent political initiative in Bonn demonstrated an unusually strong bipartisan support for the present environmentally friendly policy in the German Bundestag (Parliament).

More than 90 per cent of all wind turbines erected in Germany are owned and operated by private citizens and investors, farmers, or co-operatives. In contrast to their Danish counterparts, German electricity companies have never seen any government obligation requiring them to build wind farms.

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[16] Preussen Elektra controls the utility supply company Schleswag in Schleswig Holstein in Northern Germany, where 10 per cent of electricity consumption is covered by wind.

40. The Energy Policy Role of Utilities

The political polarisation of power companies against renewables advocates is probably politically unsustainable in the longer run. Right now an armistice prevails, since the German Parliament has decided not to touch the present legislation for another two years. For strategic reasons it is likely that the present power company attitude (displayed in public) will continue for some time, and a complicating factor is definitely the liberalisation of electricity markets in Europe.[17]

If a reform of the present system comes about, it seems likely that there will be an attempt to include some form of national sharing of excess costs of wind power, although the federal structure and the constitutional complications surrounding the regional chartered electricity monopolies makes this a difficult task. The idea of a nation-wide sharing system for utilities has been demanded in 1997 by the second chamber of the German Parliament representing the Länder, the Bundesrat. It has also been advocated by the German Wind Energy Association.

41. Market Size

At the end of 1997 close to 2,100 MW of wind power was online in Germany, making Germany the largest wind power country in the world. During 1997 a record high 550 MW (849 turbines) were added to the installed base. This is a market growth of another 18 per cent, once again making Germany the largest market for wind power in the world for the fifth successive year. Germany has increased its installed wind power capacity by ten times in just five years.

Compared with an installed base of 56 MW in 1990, before the Electricity Feed Law came into force, this is a 37-fold increase.

In the early phase of development most of the wind power was placed in the windy states (Länder) of Schleswig Holstein and Niedersachsen in Northern Germany, but increasingly development has been moving South into inland areas. More than half of the newly installed capacity during 1997 was erected in the non-coastal regions. This is partly due to a delay and administrative barriers (from a planning perspective) along the German coastline, but also due to a keen environmental interest in the population throughout Germany. At the end of 1997, the Northern

[17] It is noteworthy, however, that Preussen Elektra has recently entered into an agreement with the largest German wind turbine manufacturer, Enercon, regarding the marketing of its products abroad.

region of Schleswig-Holstein has just passed half of its own official target of 1200 MW.

42. Origin and Mainstay of the Market: Private Citizens

Wind energy in Germany has been developed by private people (non-power companies) to an even larger extent than in Denmark. Both wind co-operatives and individual farmers play an important role in this respect. More than 90 per cent of all turbines are owned and operated by private citizens.Power companies have only invested in a few very large experimental turbines, including the 3 MW Aeolus machine in Wilhelmshafen in the North.

Like in many other countries, the first 10 years from about 1980 was a long and tough haul by private idealists, who occasionally hardly had assurance that they could receive payment for the electricity delivered to the grid. Even so, some 25 MW were installed by 1989, before turbine installation took off after the Federal Government started its market development programmes.

43. The Role of Publicly Financed R&D

Germany has a strong tradition for support of large scale projects in wind energy development, mostly managed by the private sector, and culminating in the 3 MW GROWIAN machine in the early 1980s (100 m rotor diameter). That particular projectfailed when the machine, which had cost 300 million DEM (170 million USD), encountered a blade failure after only 280 hours of operation.

Large German companies like MBB and MAN were active on the scene during that period, but like their counterparts elsewhere, they left as public research money ran out.

Like elsewhere in the world, where the course was taken towards large machines only, it was difficult to get follow up funding for subsequent projects. In retrospect, the political accent on large, visible technology demonstration projects did not recognise the fundamental differences between wind turbine and aerospace technology, both in terms of the large unknowns of turbine aerodynamics and structural dynamics.

Interestingly enough, Enercon, a small engineering firm which started in 1984 without funding from the large research programme, has succeeded to become the largest German manufacturer of wind turbines, using its own gearless direct drive concept.

When the interest in renewable energy rekindled in the late 1980s, and several market support schemes were in place by 1990, as mentioned above, R&D support to private industry became an important instrument to promote German wind turbine manufacturing. The unification of Germany added another possibility of supplementary finance through regional development incentives. Industry co-operation with several university institutes, and consulting engineering firms made it possible to create a fairly large number of companies, often as subsidiaries of traditional mechanical engineering firms, such as Tacke, a gearbox manufacturer, or Husumer Schiffswerft, HSW, a shipyard.

German incentives, in fact, have been so strong and successful that they attracted the Danish manufacturer Nordex to move its turbine development to Germany (Nordex-Balcke Dürr is now majority-owned by German interests, and has manufacturing facilities in both Denmark and Germany).

44. Type Approval Requirements

Germanischer Lloyd is one of the official type approval institutes for wind turbines in Germany. (Its role has to some extent historically been similar to that of Risø in Denmark in the early years, being the anchor point for much of the infant wind turbine industry). The type approval requirements have also worked well to protect investors.

45. Turbine and Component Suppliers

In 1997 Germany accounted for about 18 per cent of world market production of wind turbines measured in MW. About half of the installed base of wind power in Germany has been supplied by domestic companies, although distinguishing between domestic and foreign turbines is not straightforward, since all the major Danish manufacturers have assembly facilities or license manufacturing in Germany, and since Nordex-Balcke Dürr is now 51% German owned.

Germany actually has a net surplus on its "wind turbine balance of payments", since the companies Flender (gearboxes), Siemens (generators), and AEG (electrical components) have very large market shares (close to 50 per cent) for their products in the wind turbine industry worldwide, including Denmark. Other components manufactured in Germany include ball bearings and roller bearings (FAG), yaw motors and gears, and yaw wheels.

The bankruptcy of Germany's second largest company, Tacke Windtechnik, in 1997 (partly due to a series of technical failures) increased the foreign market share on the German market in 1997. Tacke has since the been taken over by the American developer and turbine manufacturing firm Enron Wind Corp., a subsidiary of the energy conglomerate Enron[18.]

The German wind turbine industry today consists of Enercon, Tacke, and a dozen smaller firms, which are repeatedly going through a takeover and merger period. The two large firms account for about 85 per cent of German turbine manufacturing.

46. Employment

The German Wind Energy Association estimates that employment in the German wind industry is around 12,000 persons, or roughly equal to Danish employment in the area. German wind technology manufacturing is more directed towards the employment intensive component area than in Denmark.

47. German Technology Concepts

Most manufacturers in Germany have stuck to wind turbine designs resembling the classical "Danish Concept". The largest German manufacturer, Enercon, however, has its own multi pole synchronous generator design with indirect grid connection (using power electronics), which has managed to capture about 30 per cent of the German market, but which has failed to take major market shares abroad.

48. Profile of a Success

After a misguided start in the early eighties, the German wind energy programme has largely been a success for the past 7 years. In the view of the German Wind Energy Association, the success is largely attributable to:

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[18] Enron Wind Corp also took control of Zond, a major wind energy player, in 1997.

- the Electricity Feed Law (Stromeinspeisungsgesetz) of 1990,
- federal support programmes (100/250 MW Programme) between the early and mid-1990s,
- various support programmes by the German Länder until recently,
- preferential loan and financing schemes (investment allowances and preferential depreciation schemes), and
- privileged status for wind power in the building codes.

CHAPTER THREE

THE WIND TURBINE MARKET IN THE UK

49. Wind Resources

The United Kingdom has the largest wind resource of any country in Western Europe. The best areas, with average wind speeds from 9 to 10.5 m/s at 50 m height, are located on the coastlines facing West and South, and particularly on rounded hills with an open view in the Southwesterly direction.

The inland resource is more uneven, but generally good. Only a tiny fraction of the UK wind resource of at least 340 TWh/year has been exploited so far. [1]

50. Wind Generation Structure

Wind resources are mostlyexploited in large wind farms, and quite concentrated in the windiest corners of the country (Wales, Scotland, Northern Ireland). Parks are owned by developer companies (though often ultimately financed by power companies, who own most of the leading developers). Like elsewhere, this structure is a consequence of the institutional setup.

51. The Role of Government: NFFO & SRO

Until 1990 there was only a handful of wind turbines in the UK, which had no special regulations concerning purchasing of wind energy. Effectively that meant having to accept the electricity "pool price" of about 0.03 USD/kWh, which meant that wind energy was only economically interesting for firms with the ability to use the electricity themselves.[19] [27]

The introduction of the Non Fossil Fuel Obligation, NFFO, for England and Wales in 1990 and the Scottish Renewable Order, SRO in 1995, however, started a significant market growth in leaps and bounds. In 1997 the UK was the sixth largest market for wind energy with new installation of 55 MW.

Under the NFFO scheme the regional electricity companies are obliged to buy a certain amount of renewable based electricity. Contracts to supply the electricity are awarded on the basis of a fairly complex competitive tendering system with separate bands for different technologies. The conditions and methods of awarding (conditional) contracts and determining prices has changed between each of the (mostly) biannual "rounds", but basically contracts are awarded on the basis of the lowest price per kWh.

The changes in regulations stem largely from problems of "contract hoarding" by some developers, unnecessarily high prices due to "last accepted bid" pricing[20] and project realization time schedules too tight to cope with the extremely time consuming land-use planning process in the UK.

The producers are paid by the regional electricity utilities which in turn are reimbursed for their excess costs by the proceeds of the non-bypassable fossil fuel levy, primarily (~90%) intended to pay off stranded debt from nuclear assets (that part of the levy is being phased out at present).

Contracts are currently awarded for 15 years with indexation of the "bid price", i.e. at the price at which the contract was awarded. Earlier projects had the problem, that the long planning period shortened the period with guaranteed prices. In the latest round, a 5 year grace period has been included before the 15 year contract period begins.

52. The Role of Developers

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[19] In that case they could save the retail price of electricity, which of course is substantially higher (about 100% more) than the pool price.

[20] The >=market clearing price== approach, generally used to determine prices paid to generators in electricity power pools.

The NFFO/SRO bidding process has almost become a science of its own, and the vast majority of market players are UK developer companies, mostly subsidiaries of large power companies, but also some independent developers and a few wind turbine manufacturers. It is worthy of mention that because developers buy from wind turbine manufacturers on a competitive basis, manufacturers tend to stay away from the bidding process, not wanting to compete with potential customers.

For all practical purposes, non-manufacturer developers today form the core of the UK wind industry, and one consulting engineering firm has had some success in developing considerable engineering expertise in this area.[21]

This developer "layer" is a fairly unique feature of the UK market, although it is similar to the US wind development, particularly in California.

53. **Planning Procedures**

The growth of the developer sector is partly a result of the UK bidding process, partly a result of the very long and complex planning procedures and environmental assessment system used in the UK. Wind farm projects often take up to 5 years from the bidding stage to the operational phase, creating some awkward results in the process.

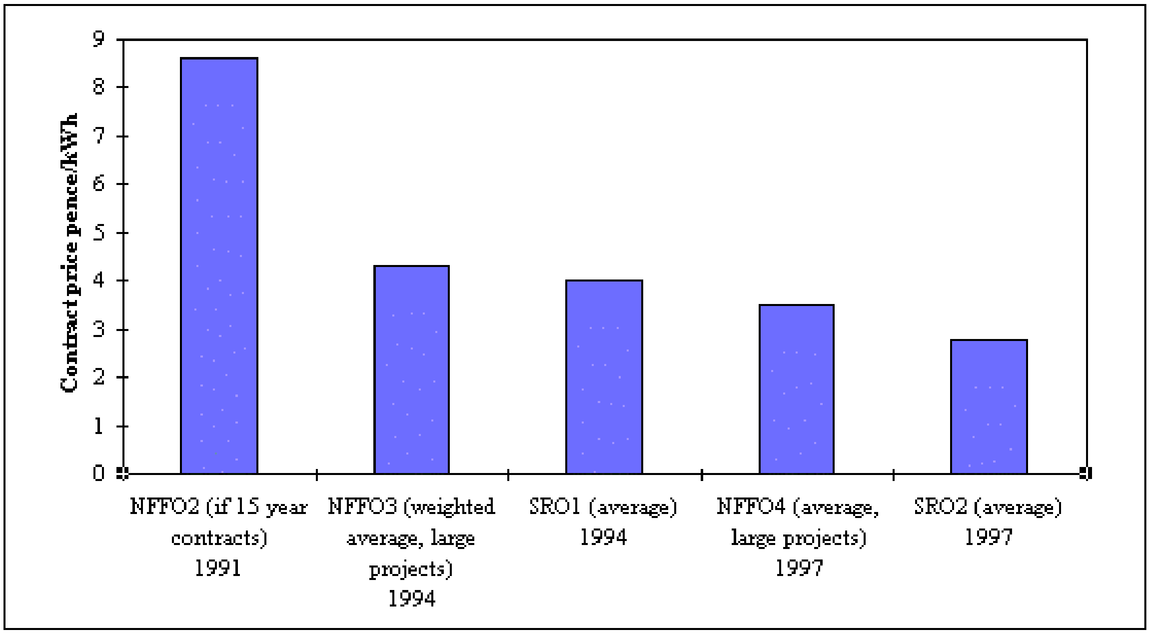
For example, projects originally designed for 300 kW machines have matured around the time when the 600 kW generation of wind turbines is the most economic solution, with the result that turbines have to be placed on extremely low custom made towers to fit the dimensions originally applied for in the local planning process.

Another peculiar feature of the interaction between the UK planning system and the competitive bidding process is the "clustering problem": The tough competition between developers for low kWh prices means that wind prospecting, far from being almost a public good, as in Denmark, becomes an important competition parameter. Each developer runs his own wind measurement programme, and for simple geographic reasons developers tend to end up in roughly the same windy corners of the country. If several developers win contracts on adjacent sites, only one will proceed (at the most), since planning authorities apparently use an unwritten "interpark visibility rule" according to which

[21] Garrad Hassan & Partners.

one should not be able to see a wind park from an adjacent one.[22]

More than 700 MW of contracts have been awarded under the NFFO system, which have not yet materialised as actual projects. The success rate for contracts is estimated to be around 30% to 50%, due to the planning and environmental assessment procedures.



54. **Pricing of Wind Energy**

The kWh price for contracts has been declining considerably during successive NFFO rounds, arriving at figures around or below 0.05 USD/kWh. The graph below gives the weighted average of costs in UK pence per kWh for each of the succesive NFFO and SRO rounds. The figures have been normalised to represent 15 year contracts (which is the rule today) [29].

The decline in prices reflects the universal decline in wind energy costs in all countries, and is discussed further in the conclusions. The price decline, however is more visible in the UK, because it does not operate a fixed renewables tariff system like Denmark, Germany, or Spain. In the last three countries, the cost decline has primarily been reflected in growth in turbine installations, because it

[22] In general, visual aesthetics are the only major issue with planning authorities in the U.K.

has become economic to install turbines on many more sites.

55. Grid Connection, Grid Reinforcement

These costs are part of project costs for the developer.

56. Market Size

The total installed base of wind power was some 328 MW at the end of 1997. 55 MW were installed in 1997, against 73 and 40 MW in the two previous years.

57. Turbine and Component Suppliers

Britain has been home to a number of small, and fairly innovative wind turbine manufacturers including Carter, and WEG, (Wind Energy Group). The companies have failed to win major sales; Carter, a manufacturer of a flexible 2 bladed downwind design, folded in 1996, while WEG, a manufacturer of two bladed machines, was resuscitated about 1995, following an initial bankruptcy. The firm made a comeback with a 3 bladed "soft" downwind design which has as yet apparently failed to win major sales. The company was acquired by Danish NEG-Micon in 1998 together with its sister company Taywood Aerolaminates, makers of wood epoxy blades, and suppliers of blades for the 1.5 MW NEG-Micon machine. Brooks Crompton (a generator manufacturer) is another example of a (smaller) turbine component manufacturer.

58. Employment

The British Wind Energy Association, BWEA, estimates that around 2000 jobs are created directly and indirectly by wind power development in the UK. In general, job creation opportunities have not materialized as much as elsewhere. This is due largely to the low project success rate discussed above, which increases the costs and risks of doing business. Most foreign wind manufacturers have prefered to export turbines and components rather than set up manufacturing facilities in an unstable market.

59. **The Home Market's Role in Industry Development**

Job creation in the UK market has primarily been in the tertiary sector, i.e. development, consultancy, finance, legal, and planning issues - plus, of course, installation work. This latter component has been quite significant, given the often difficult accessibility of UK sites in high wind areas.

60. **Assessment of the UK System**

The UK system is generally considered successful in bringing prices down by British developers, and a number of foreign observers who point out that the bidding process ensures a very effective use of public funds.

The drop in kWh prices in successive NFFO rounds may partly be due to increasing competition, but there is probably also an element of speculation in future price reductions for wind turbines, given the 5 year grace period. Another element in low prices may be advantageous financing from utilities.[23] Finally, privatisation of the regional electricity companies increased their capacity to absorb larger depreciation allowances from capital investments.

From a planning perspective, however, the system has been less successful, since it is very difficult to predict from the beginning of the bidding process which projects will end up receiving planning permission in the end. Therefore, there is also a very substantial uncertainty looming over the number of MW which will actually materialise as real projects out of each bidding round.

The relative lack of predictability and stability of the market, coupled with low project success rates due to geographically-overlapping bids, has made it difficult for turbine manufacturers to justify using the UK as a manufacturing base. Furthermore, the size of the market is definitely below the critical mass required for it to work as a base for a national manufacturer.

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[23] Most of the the leading developer companies are owned by the electrical utilities. These companies have been particularly successful in successive NFFO and SRO rounds. Judging by their bids, it appears that they have access to cheaper finance than other players. The privatisation of utilities also led to a number of utilities having a large capacity to absorb depriciation allowances. Finaly, it seems likely that utilities (like in many other countries) do not wish their core business (power generation) to be taken over by other players.

The level of intermediation (the developer, legal, and consultancy layer) is clearly higher in the UK than elsewhere. The complex UK planning process definitely increases costs. It is not entirely convincing that the UK NFFO system should be more efficient from an economic (social cost) point of view than systems in other countries, particularly if one considers the very high wind speeds in the UK.

The problems of the multi-stage procedure (conditional contracts without final planning approval) makes it extremely difficult to predict the final outcome of the NFFO rounds.

CHAPTER FOUR

THE WIND TURBINE MARKET IN SPAIN

61. Wind Resources

Spain has excellent wind resources, particularly in Andalucia facing the Southern Mediterranean, and in Galicia, Aragon and Navarra in the North, facing the Bay of Biscay. [1] These regions tend to be quite hilly or mountainous, thus adding an important component of speed up effects to local wind speeds.[24]

62. Wind Generation Structure

Wind generation in Spain is located in (usually very large) wind parks in the windiest areas of the country, where the density of parks is quite high, particularly around Tarifa in Andalucia (at the Strait of Gibraltar). The development of wind energy in Spain started in 1991, but picked up speed around 1994. About 500 MW were installed at the end of 1997. Approximately 250 MW were added to capacity in 1997, and another 250 MW are expected for 1998 [23].

63. Energy Policy for Wind

The National Government has not set a declared target for wind, but several provinces in strongly federalised Spain have set very ambitious targets, as mentioned in the next section.

The Spanish system for support to renewables is in many ways similar to the German system, i.e.

[24] Typical wind speeds of 5.5 to 6.5 m/s at 10 m height are therefore not a good guide to actual wind speeds at wind turbine sites, which may be substantially higher on ridges.

an open-ended system with guaranteed prices from utilities, and guaranteed power purchasing by the utilities in the national grid. Wind and solar in 1997 received 12 ESP/kWh (0.065 USD/kWh)[26].

Unlike the German system, the excess costs of the premium payment system is spread on all electricity users nationally. The system is very similar to the German system, but the whole spanish national electric system has always had a compensation and equalisation system under which distribution companies are required to balance revenues and losses. Spain has a common national grid, which Germany does not.

It is planned that the system will be changed to a system which gives each technology a premium over the electricity pool price, rather than a fixed amount per kWh. (The pool price is currently around 9 ESP/kWh (0.05 USD/kWh)). The premium should reflect the relative environmental benefits of each technology, much like the present Danish system. In addition, a competitive bidding system is envisioned for large wind parks above 50 MW. No details on the future policy are presently available.

64. The Role of Regional Governments

Regional governments are in many ways taking the lead in promoting wind energy in Spain. [30] Regional governments are responsible for planning, and actual planning permits are issued by the municipalities.

In the North, Navarra wants to cover 100% of its electricity consumption from renewables in 20 years' time. By the year 2000 wind should cover 25% of local electricity consumption (roughly 220 MW), the total being tripled to more than 600 MW by 2010.

Galicia wants 2,800 MW to be installed by 2010, a figure which according to many observers may be too optimistic, given that the present grid capacity is around 600 MW. A strengthening of the grid is, however, being planned.

As a member of the European Union, Spain is of course obliged not to discriminate on the basis of nationality, and there is a free circulation of goods in the Union. Spanish provincial governments, however, attach considerable weight to local employment, and with their strong hand on planning permissions, have managed to entice many foreign companies to establish joint-ventures with local industry.

According to one leading observer: "Regional support in terms of cutting red tape in exchange for new jobs in their region, seems to be the solution in most parts of Spain".

65. **Wind Resource Mapping**

Spain has a national wind map, but its level of detail and quality is apparently insufficient for actual planning work.

66. **The Role of Developers**

Large, international wind turbine developers are increasingly dominating the picture in Spain. The major market actors are Seawest (USA), Tomen (Japan), Endesa-MADE (Spain), and Iberdrola (Spain). The Spanish market is generally dominated by professional developer firms, much like the UK.

67. **Turbine and Component Suppliers**

Spain accounts for about 14 per cent of the world production of wind turbines (1997), and three Spanish firms are now on the list of top ten manufacturers worldwide, i.e. Gamesa, Endesa-Made and Desarrollos with world market shares around 6, 5, and 3 per cent respectively. The three firms accounted for around 85 per cent of wind turbine installations in Spain in 1997. [23]

Spain's largest manufacturer with a 36% share of the local market is Gamesa Eòlica founded in 1994, which uses technology from Vestas Wind Systems, and is a joint venture with 40% Vestas ownership, while the other two shareholders are a regional development corporation, and a company group manufacturing car and aircraft components.

Endesa-Made and Desarrolos have market shares of 29 and 21 per cent. Endesa is a utility, which owns the turbine manufacturer Made. The design looks remarkably like a classical (1985) Danish design. Desarrolos was originally a joint venture between the Spanish manufacturer Abengoa and U.S. Windpower (U.S. Windpower later became Kenetech, which went bankrupt in 1996). These two companies and the fourth Spanish manufacturer, Ecotèchnia, have their own technology which is basically variations on the Danish concept.

Other companies have been or are being established in Spain, and some 80 companies are estimated to take part in supplying components or services to this industry. Danish NEG Micon, which has already been engaged in Spain through the joint venture Taim-Nordtank is currently establishing a factory in Galicia in Northern Spain, while Danish Bonus Energy has entered into a joint venture with a government-owned company, Bazàn which is known for its manufacture of ships for the Spanish navy, diesel engines, steam turbines, and weapons systems. In 1997, after only two years of operation, this company had captured 15% of the Spanish market.

Component manufacturing is growing rapidly in Spain. The world's largest supplier of rotor blades, LM Glasfiber is now operating three plants in Spain, and one of ABB's two European wind turbine generator factories is located in Spain.

68. **Employment**

No estimate has yet been made of the employment impacts of wind energy is Spain. However, it is noteworthy that most outside wind manufacturers have established manufacturing facilities and in some cases entered into joint partnerships, as this inevitable maximizes job creation in the host country.

69. **The Home Market's Role in Industry Development**

The Spanish home market presently takes all of the production from Spanish manufacturers. Given the strong domestic market growth of 90% per year over three years, and the fact that most firms were established recentlythis is hardly surprising. In the longer term, Spain sees itself as a natural stepping stone to South American markets for wind power development.

70. Assessment of the Spanish System

Spanish wind power development has been a dramatic success in terms of creating much local employment. In time, Spanish wind turbine companies may be able to benefit on other markets from the experience acquired during these boom years.

Despite a financing system roughly similar to the German regulations, the Spanish system creates less of a problem for power companies, since costs are shared nationally.

CHAPTER FIVE

SOME THOUGHTS FOR QUÉBEC

71. The Bare Essentials

The basic requirement for establishing a viable local industry is that there is a driving force in terms of a local market of a significant size in sight. This is particularly true for goods for which there are high transport costs, such as wind turbines.

It appears that a threshold value of more than a hundred megawatts nameplate capacity per annum (perhaps 100-150 MW/yr) is a key figure for local joint ventures with foreign partners, or local manufacturing by foreign companies.

Stability and predictability are Asine qua non@ conditions for attracting foreign investment. A commitment for at least 5-10 years is essential. The UK case underscores this, in the sense that there are large promises of future contracts, but great uncertainty about which projects materialise. With a 50 MW very competitive market, no foreign manufacturer has found it worthwhile to invest there, and nearly no domestic manufacturers have been able to survive.[25] Likewise, the primary component suppliers for the European wind turbine industry are not to be found in the UK.

Wind turbine component suppliers in Europe are primarily located in the major manufacturing countries: Denmark, Germany, and increasingly Spain. Despite a foreign market share of around 50 per cent on the German wind turbine market, Germany has a healthy net export of wind turbine components to e.g. Denmark. There is an important technology feedback between turbine manufacturers and their suppliers.

Conditions vary from country to country, of course, and turbine manufacturers are used to

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[25]The exception being Taywood Laminates and WEG, which were resucitated by their owner Taylor Woodrow, as mentioned in the UK case study. These two companies have now been acquired by NEG Micon, (though only Taywood Aerolaminates for manufacturing purposes).

dealing with different national systems. It may be interesting, however, to indicate the views of manufacturers elsewhere: In a recent[26] official meeting between Chinese authorities and the Danish Wind Turbine Manufacturers Association, the Danish manufacturers made a joint declaration outlining the preconditions for local joint ventures very briefly thus:

- There must be a clear Government policy for wind
- There must be a regulated power purchasing system for utilities
- There must be sufficient confidence to draw up a medium-term business plan
- It is useful to have a local network of subcontractors for components
- There must be a recognised testing/approval procedure for introducing and approving alternative components for turbines
- Regulations for establishment, investment, and operation of joint ventures must be clear
- Finding the right partner for a joint venture

72. **Employment Creation from Wind Energy**

Like Hydro, wind is characterised by relatively large investment outlays up front, but low running costs. Typically, installed generating capacity in MW has to be 2 to 3 times larger than for comparable thermal plant for the same annual energy production, and roughly twice the size of most Québec hydro facilities (which tend to be operated at a capacity factor of roughly 60%). The reason is that the capacity factor for an optimally built wind turbine generally turns around 25 to 30 per cent.[27] Expanding generating capacity using wind will therefore lead to larger (and immediate)

[26] 21 April 1998, in Beijing.

[27] Technically, one may build a wind turbine with a higher capacity factor by fitting it with a smaller generator for the same rotor size. This means that the machine will be running during more hours of the year, but its total annual energy production (much of which comes at high wind speeds) will be substantially lower.

employment effects than many other technologies.

73. **Direct and Indirect Employment Creation from Turbine Manufacturing**

Global job creation from the manufacturing of large wind turbines is currently estimated to be around 16 to 18 jobs per MW.[28, 29] This figure includes job creation with subcontractors (generators, rotor blades etc.) and "sub subcontractors" (steel, copper, plastic etc.), in all links (in principle ad infinitum) in the global supply chain. However, the figure does not include knock-on effects in the local economy (multiplier effects) due to workers in wind turbine factories spending their wages, etc.[30] The figure does not include turbine installation work, which is treated separately below.

The national employment impact will be smaller than the previous estimate, due to division of labour in the world economy. Calculating the regional or national impact requires an input output model of the regional or national economy. In the case of Denmark, it can be estimated that 1 MW of turbine manufacturing (in 1998) creates 10 jobs directly and indirectly.[31]

The direct job creation within turbine manufacturing firms varies considerably, depending on whether the manufacturer is vertically integrated or not. Using the method from [18], however, gives important clues about where the jobs are:

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[28]We use the term >=jobs== hereafter to indicate >=job-years==.

[29]The methodology is developed in [18], using input-output analysis. The author=s estimate is based on his previous study from 1995, with (real) productivity updated by 3 per cent per annum. The calculation is based on a 117 sector input-output model of the Danish economy developed by the Danish National Statistical Agency, and updated annually. The calculation assumes the same manufacturing efficiency of components and services throughout the world as in Denmark. The estimate is based on the most cost efficient machine class, i.e. the 600-750 kW class (which contitutes 80-90% of the current market).

[30]The reason for not including this secondary impact is, that if all industries calculated their employment impact that way, we would end up with far more than total world employment.

[31]This is roughly equivalent to saying, that for a sales value of 100%, about 60% is *Danish* value added, while 40% is directly or indirectly imported. To recalculate this figure for other economies, as a rule of thumb, increase the import propensity for smaller economies (countries or regions), decrease it for larger, more diversified economies. (A significant share of smaller countries= foreign trade would be internal trade in a large country).

Estimate of Direct + Indirect Employment Distribution in Wind Turbine Manufacturing 1993[32]

Component	%
Generator	6
Gearbox	12
Rotor blades	12
Tower	16
Brakes, hydraulics	2
Electronic controller systems, remote surveillance	4
Turbine assembly, design, sales, etc.	17
Residual, e.g. hub, yaw mechanism and electrical equipment	22
TOTAL	**100**

When interpreting this table it is important to keep in mind that it includes both direct and indirect jobs from component delivery. E.g. the number of jobs in a generator factory will depend on the degree of vertical integration in the production process. Conversely, turbine manufacturers who make their own blades and controllers may have a higher employment than the 17 per cent average indicated here. Rotor blade manufacturing is presently a rather labour intensive process, but there are significant differences in the degree of vertical integration between firms (e.g. related to the use of semi finished products (prepreg).

74. Direct and Indirect Employment Effects of Turbine Installation

Installation of wind turbines gives jobs in the local economy, particularly in road and foundation

[32] The figures cannot be derived directly from [18] since a number of corrections have been made for components left out of the study, e.g. yaw motors & gears, and a number of electrical components, hence the residual. Also, the cost of generators has been updated. Danish manufacturers are probably at the low end of the employment estimate due to relatively larger machine sizes and higher efficiency.

construction, grid connection, work etc. Using the analysis in [18], we may calculate a (local/national) employment for Denmark of some 4 jobs (directly + indirectly) per MW, and 5 jobs globally (for 1998).[33] For areas with more difficult access to sites, such as the UK,34 installation costs are typically more than twice as high as in Denmark, yielding an employment of 8 jobs locally and 10 jobs globally.[35]

75. **Summary on Employment**

The installation of 1 MW of wind energy will create approximately 21-28 jobs in direct + indirect employment globally (in 1998). Of these, 16-18 jobs are created by turbine manufacturing, and 5 to 10 jobs by installation work. At a national level, employment impacts will likely be in the range of 13-22 jobs/MW.

This estimate of the number of jobs is on the cautious side, if anything, since it is based on Danish data with large machines, large industrial experience, a strong electrical grid, and fairly easy access to wind turbines sites.[36] Also, these estimates do not include knock-on (multiplier) effects in the economy.

Turbine assembly is a relatively minor part of the entire value chain, but broadly, 1 job in a wind turbine factory creates about 4.5 jobs with component suppliers (and their sub suppliers) domestically. [32]

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[33]The calculations assume total installations costs of 27 per cent of turbine costs. The installation costs (and employment effects) may be higher or lower, depending on the accessability of the site, and the size of the turbine. (There are economies of scale, mostly in relation to turbine size,and often in relation to cluster or park size). Note that the import content of installation work is generally quite small.

[34]The estimate of UK installation costs is taken from [31].

[35]The high installation costs in the UK are mostly due to the fact that wind parks tend to be located in sparsely populated areas, requiring substantial grid reinforcement and access roads though peat bogs. The fact that these areas have extremely high wind speeds compensates for the high installation costs, thus yielding faily low electricity prices.

[36]A useful way of veryfying this is to check the figure for value added per person employed. It should be lower than in manufacturing, which a high-productivity sector of the economy. On the other hand, it should be closer to the value for manufacturing, than the overall average for the economy. Wind turbine prices for large machines are currently around 750,000 USD/MW in Europe at the time of writing (1998).

76. **The Market for Wind Turbines**

Today, more than 7,600 MW of wind power (rated nameplate power) have been installed worldwide, in a rapidly accelerating manner, with more than half being installed during the past four years. Presently, about 1,600 MW is installed per year. Market analysts expect an annual growth rate of sales around 15-20% per annum over 5 years. [24]

The commercial market for wind turbines is completely dominated by the so-called "Danish concept", a 3 bladed horizontal axis upwind machine with an electromechanical yaw system, and direct grid connection of an induction generator. This accounts for around 70-80% of the world market. 3 bladed upwind machines with synchronous generator and indirect grid connection account for around 15%. The remainder is two bladed designs, plus a handful of one bladers. Canadian research institutes played a leading role in large scale research and development of vertical axis wind turbines, but unfortunately, like a number of other countries, Canada concentrated exclusively on a single design and size class, which so far has had little commercial success.[37]

National markets vary widely, both in terms wind resources, rules and regulations, and even the basic motivation for using wind energy. Broadly speaking there are two sets of markets: The developed countries, which primarily invest in wind energy for environmental reasons, and the developing countries, which basically invest in wind energy for economic reasons. Wind energy provides generating capacity that can quickly be brought online, subsequent operating costs are low, and no fuel imports are required. China is currently the fourth largest market for wind power in the world after Germany, Denmark, and Spain.

Danish, German and Spanish wind turbine manufacturers account for more than 90% of global wind turbine manufacturing.[38] Danish manufacturers have a 58% global market share. For this reason, Denmark, Germany, Spain, and the UK are investigated more thoroughly in the reports annexed.

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[37] The last remaining manufacturer of vertical axis machines, Flowind, went bankrupt in 1997, due to a failed export venture in India. Most of the remaining commercial vertical axis machines were demolished in 1997 (in Altamont, California). [40]

[38] Zond (US) had sales of 2.4% and Wind Master (Dutch) had sales of 1.6% of the world market in 1997.

77. **Exports or Local Manufacturing**

The average export share for the 11 largest wind turbine manufacturers in the world has been some 50 per cent during the past three years. [23] Danish companies have been in the lead with export shares between 50 and 90%. German manufacturers have had export shares around 10%, whereas the new Spanish manufacturers have not yet developed exports. Developing a new export market is a long process, often lasting 3 to 5 years or more.

Wind turbines are large and heavy pieces of machinery, and transport costs are a significant factor in international competition. When larger series of turbines are being installed, it has become fairly common practice to manufacture towers locally.

Local manufacturing of towers is often a first step towards a more permanent presence as a manufacturer, if a stable market of a reasonable size is being developed. China is a case in point, where power purchasing agreements and other institutional arrangements have been put on a permanent footing. In 1997 more about 100 MW were shipped to China by several large manufacturers, mostly in continuation of projects started on a smaller scale 3 to 5 years ago. [23] Several large manufacturers have signed agreements on join ventures, which may be expected to materialise within a year or two.

Rotor blade manufacturing is one of the more labour intensive processes in the industry. In a country like Spain, where most manufacturers source rotor blades from suppliers, three rotor blade factories have been established within the past three years.[39]

About 100-150 MW annually seems to be an interesting threshold for local turbine manufacturing, in particular if further market development is envisaged. Such was the case in Spain, and also in India.

Two years ago, however, the Indian market collapsed triggered by an election, and dramatic increases in interest rates. India had by then developed its domestic industry, largely on the basis of technology transfer from Europe, and quite a large domestic production. India, however proved how dangerously unstable export markets can be, and several manufacturers, large and small, suffered substantial losses, which in several cases led to bankruptcies (of smaller companies). The market now appears to be coming back to normal, with a production rate somewhere around 100 MW (Indian

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[39] The Danish company, LM Glasfiber is the world=s largest rotor blade manufacturer, and has established three factories in Spain.

statistics are highly uncertain). The Indian experience has raised the consciousness of manufacturers regarding the importance of market stability.

Foreign joint ventures in Spain did not materialise until a set of rules with a 5-year horizon, and a renewal protocol was set up. [26]

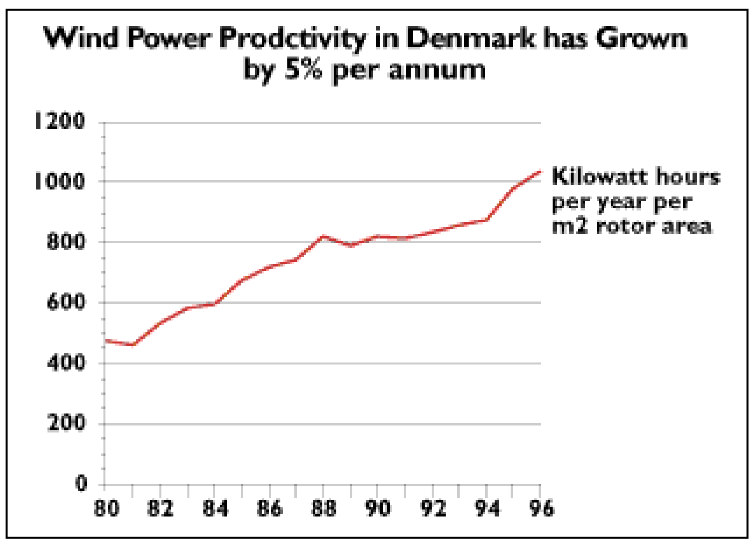
Large turbine manufacturers generally prefer sourcing major components from at least two suppliers, in order not to become overly dependent on a single supplier. Changing components however, requires a new type approval, so supplier relationships tend to be rather permanent after a testing period. The complex design, testing and type approval requirements for wind turbines imply that it often takes some time to phase in new components. Consequently it cannot be expected that newly established manufacturers or joint ventures will be able to have a very large local value added, before some running in period.

Local partners in turbine manufacturing joint ventures are often machinery and equipment manufacturers who have suitable tooling and skills.

78. **Cost Decline for Wind Energy**

Competition is increasing, and costs are coming down rapidly in the wind industry around the world, as illustrated e.g. by the experience from the U.K.[40] There are several reason for this development:

Wind turbines are getting cheaper: E.g. the catalogue price of a typical Danish 600 kW wind turbine today is exactly the same as that of a 500 kW wind turbine 3 years ago, and the new models typically include towers which are 5 to10 m taller for the same price. [33]



The productivity of new wind turbine generations is increasing all the

[40] See the illustration in the paper on the UK market.

time. This is clearly demonstrated in the case of Denmark, where the annual energy yield per square metre of rotor area has grown by 5 per cent per annum since 1980, as shown in the graph above.[41]

There are many reasons for this rapid development in wind turbine productivity. The technology appendix gives 15 characteristic examples of technology improvements on the 600 kW generation of wind turbines, since they were introduced 3 years ago. All examples are taken from the 5 large Danish manufacturers' machines.

Machines are continuously being upscaled, particularly in Northern Europe. This has lowered installation costs per kW installed to a quite surprising extent. (Installation costs per kW installed have dropped by about 33% between the 225-300 kW and the 600 kW generation of wind turbines in Denmark). [34, 35]

Lower interest rates have improved the competitiveness of this capital intensive generating technology.

79. **Hydro-wind perspectives from Scandinavia**

Wind and hydro are much more complementary than wind and thermal electricity generation: Hydro systems give a very cheap and efficient backup to wind generation, and hydro systems may consequently accommodate larger amounts of wind power with a lower cost than thermal systems.[42] Another way of stating this is to say that for a hydro operator, wind acts like extra streams and rivers added to the existing reservoirs. In most parts of the world, the windy season and the rainy/snow-melting season are negatively correlated, thus adding to the effective capacity of the reservoirs.

An interesting perspective on this may be found in the Scandinavian electricity supply system,

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[41] The increase is measured from first year production from a sample of new machines installed every year since 1980. Since the wind climate varies slightly from year to year, the production figures have been normalised to an average wind year. The calculations were done by Energy & Envrionmental Data, on the basis of the Danish Wind Turbine Owners' Association data base. [Published in the quarterly magazine Energie & Miljødata]

[42] The best sources for an economic analysis of running wind power in a predominantly hydro and nuclear system are the works of Lennart Söder, Technical University of Stockholm, who has made a number of studies of the Swedish electricity and energy supply system. [36] (Sweden is in the process of phasing out nuclear energy after a referendum).

where Danish plans for 50 per cent wind energy by the year 2030 has been analysed extensively by the two large Danish power company groups and Risø National Laboratory. [37] From this analysis, and from a new report focusing exclusively of the economic gains from running the Norwegian (99 per cent hydro based) and Danish (in future 50 per cent wind based) systems in tandem, it appears that the economic gains from this are quite important.[43]

Norway is presently is a phase where additional capacity has to be added to the generating system, (and or energy savings have to be made), since it is environmentally difficult (and now, marginally becoming more expensive than wind) to add more hydro to the system.[44]

Two large gas fired power plants have been stalled in Stortinget (Parliament), because of concerns about increasing Norway's CO_2 emissions, and Wind is now firmly on the agenda of Stortinget. [39]

Judging by the oversubscribed conferences on wind this spring (Organised by the NHO, Federation of Norwegian Business and Industry, and Vestlandets Vindkraftforum), energy corporations, manufacturers, and consultants are flocking towards what almost looks like a Klondyke for wind. (cf. also [18]) It is interesting to note the strong political support for wind energy development from the Federation of Norwegian Business and Industry, in view of the fact that it also represents the most electricity consuming companies in aluminium, ferromanganese smelting, and the forest industry.

Norwegian industry is not lacking ambition: Kvaerner, a large shipbuilding, offshore technology, and machinery manufacturer, has declared in the press that it intends to become the largest wind turbine manufacturer in the world, developing muli-MW machines, and has acquired a small Swedish turbine manufacturer a few years ago.[45]

The Norwegian Government is planning a wind investment support programme, and actual development will hinge on this, since all parties realise that wind is not economically competitive at

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[43]The report simulates reservoirs, weather patterns, and behaviour of the Nordic electricity exchange. [38]

[44]Stated by Rune Valle, Naturkraft (electricity broker), at the Conference for Norwegian electricity exchange brokers, Arendal, 1996. It appears that a few hundred MW additional capacity are available at lower average generating costs than wind, but the remaining reservoir potential appears to be mostly smaller reservoirs in regions which are expensive to access.

[45]The declarartion was made more than a year ago in the Norwegian and Danish press. Since then, the company has remained remarkably silent on the issue.

present despite relatively high wind speeds.[46]

The reason for bringing wind into the system is to improve the future CO_2 situation cheaply. From the statements by the Oil and Energy Minister it would seem that an implicit initial target may be some 100 MW nameplate power per year. (Probably effective in about 3-5 years' time in the opinion of this author).

Sweden is currently expanding its wind energy programme, since it is starting to close a number of nuclear power stations beginning this year (1998). A medium sized offshore (38 MW) project may start in 1999.

The future energy system of Sweden is currently under discussion, and in case wind gets to play a major role, it will probably largely be through offshore development, since onshore wind resources are very modest.

[46] Indicated in [39] and restated by the Minister for Oil and Energy and the State Secretary for Oil and Energy at the two conferences, and during the Norwegian Parliament Energy Committee Mission to Denmark, March 1998.

APPENDIX

PRODUCTIVITY GAINS FROM FIFTEEN RECENT TECHNOLOGICAL IMPROVEMENTS

The following fifteen examples of technological improvements leading to productivity gains are all taken from the recent (1995-97) experience with 600 kW series Danish wind turbines.

One reason for higher production from Danish wind turbines is the fact that tower heights keep increasing, partly due to cheaper towers. More advanced tower design modelling methods have allowed about 40% savings in the use of steel.[47] An increase in tower height from 40 to 50 m will typically increase energy output 6 to 8 per cent. Much of the productivity increase in later years in due to this factor.[48]

Another reason is that more advanced engineering methods allow the use of larger, less solid rotors for a given generator size.[49]

- Improved aerodynamics allows a more efficient power control of wind turbines.[50]

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[47] Towers cannot (profitably) be designed separately, because they are part of the dynamic strucure of a wind turbine, and their properties (stiffness, eigenfrequency, fatigue properties) have to be optimised for each turbine model, to save on materials. To get an idea of the degree of optimisation which is possible one may compare a Danish 600 kW Bonus Mk IV Machine, and a German 600 kW Tacke TW600 machine, both on 50 m towers: The Bonus machine is 40% lighter.

[48] The increase in energy output varies with terrain roughness, i.e. the higher the roughness (e.g. the more trees and bushes), the larger the productivity gain from taller towers. The 6 per cent increase corresponds to roughness class 1. The 8 per cent increase corresponds to roughness class 2 (as defined by the European Wind Atlas method). The increase is calculated for a Rayleigh distribution of wind speeds. For calculation methods, see the wind resource section on the www.windpower.dk web site. For applicable theory, see [1].

[49] The solidity of a rotor is the ratio of the rotor blade (frontal) area to the total rotor area. The reason why it is desirable to decrease rotor solidity is to decrease the dynamic loads of extreme winds and gusts on the structure. The use of more advanced load and strength calculation methods makes it possible to make a more realistic safety calculation, which permits designers to ensure a uniform level of safety throughout the tubine's design.

[50] The use of aerodynamic improvement devices such as vortex generators on rotor blades may add 2 to 5 per cent to

- (Partial) variable speed operation allows the design of lighter turbines.[51]
- Improved generator design allows more optimal power control of wind turbines, increasing both yields and electrical power quality.[52]
- More advanced electronic controller systems allow higher energy production.[53]
- The use of power electronics allows (partial) variable speed operation and better control of power quality on weak electrical grids.[54]
- Basic research and better design methods allow manufacturers to move much closer to theoretical limits of material properties.[55]

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annual production of stall controlled wind turbines. In addition, with more well defined stall characteristics it is possible to make better a design basis for gearboxes and generators, and thereby a more overall optimal design.

[51]Variable speed operation allows the wind turbine to temporarily store excess energy from gusts as rotational energy in the rotor. The most important gain is that the tower and rotor can be built lighter and more flexibly. It also reduces peak torque in the power train importantly. It also improves electric power quality (e.g. flicker).

[52]The introduction of variable slip induction generators allows optimal power cotrol of pitch controlled turbines. The essence of the method is to allow gusts to increase rotational speed by increasing generator slip in a matter of miliseconds. The control system operating the active blade pitch mechanism then gets a longer time interval to handle the situation, and generator slip can be reduced again. This allows the turbine to run constantly exactly at rated power at high wind speeds. The ingeniousness of the system is that it operates without slip rings on the induction generator, but with internal optical transmission of generator slip requirements to electronics which is mounted on the rotor together with a variable resistor bank. To understand this, you need to be familiar with generators, e.g. by reading the generator section on www.windpower.dk.

[53]Better control algorithms on pitch contolled machines allow a simultaneous reduction of both peak torque and higher energy production.

[54]This allows relatively large turbines to operate without grid reinforcement on remote power radials.

[55]Research into the interaction between aerodynamics and structural dynamics (usually called aeroelastics) has improved the understanding of the dynamic properties of these (the world's largest) rotating structures. New advances in computational fluid dynamics, CFD, in particuar 3D modelling of airflows around rotor blades, (which is virtually unknown in the aircraft industry), has improved the understanding of a number of important phenomena, in particular stall and deep stall. (The aerodynamic phenomenon stall is used deliberately in wind turbine design, whereas it is avoided at all costs in the aerospace industry). Much of this research has been incorporated into better mathematical and statistical modelling tools for turbine designers.

Improved wind resource analysis models (WAsP), better professional wind software for airflow calculation (WindPro), and detailed digital maps have raised productivity and accuracy in wind prospecting dramatically. (The development of the original European Wind Atlas Method accounted for a significant part of the productivity increase (almost 50%) in the early 80s).

Site-specific optimisation of the ratio between rotor diameters and generator size has improved productivity per installed kW by up to 40% (for typical low wind sites in Germany). This has been possible through a much more modular approach in manufacturing (e.g. hub extenders and modular towers), and considerable economies of scale in the manufacturers' handling type approval requirements.[56]

Improved measurement methods and manufacturing techniques, and basic research in aeroacoustics, in particular related to blade tip geometry have lowered noise by some 3 dB(A), i.e. 50 per cent within the past three years for typical Danish rotor blades. Since Danish wind turbines in this decade have had no problems meeting legal noise regulations in the marketplace, manufacturers have used the noise advantage to increase rotational speed slightly, thus increasing energy production by about 1-2%.

After extensive research, acoustic resonance within the wind turbine structure itself (the rotor acting as a loudspeaker membrane) has been reduced considerably using new combinations of rotor blade materials.

New lightning protection methods have been developed after the study of thousands of lightning strikes hitting wind turbines (or the grid to which they are connected).[57]

A new generation of large (and less expensive) rotor blades has been developed using wood epoxy

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[56] Each and every combination of tower height, rotor diameter, generator size, or a change in electronic control systems requires a complete type approval of the entire machine. This is necessary to ensure e.g. that the dynamic properties of the machine are stable and safe under all conditions in the specific wind climate for which it is approved. (Wind climates are defined by average and (50 year) extreme wind speeds, and turbulence conditions). The large Danish wind turbine manufacturers have their own internal type approval units who verify design methods and have experience in dealing with the different accredited type approval authorities.

[57] This is not just a case of building conductors into rotor blades, but it is now an integral part of the whole design process, because lightning may hit and disable quite unexpected parts of the wind turbine.

technology, as an alternative to glass fibre reinforced polyester or epoxy.

New design methods have been developed and implemented to deal with the aeroelastic behaviour of large stall controlled rotors. (The methods have been developed after extensive research by both companies and public research institutions, and measurements on a large number of machines in special wind climates.)[58]

[58]The methods are concerned with edgewise oscillation phenomena and multi-stall behaviour of classical airfoil profiles.

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