European Commission
Directorate-General for Energy

WIND ENERGY - THE FACTS

Volume 1

TECHNOLOGY

EXECUTIVE SUMMARY

Introduction
The technology volume reviews:

- the wind resource which is the basis of all wind energy developments
- state of the art of European technology
- research and development requirements

Resource
In 1995, electricity production in the EU amounted to 2384 TWh. The estimated annual wind potential is 588 TWh (land based resource) which is adequate for a 20% penetration of supply. This excludes the annual offshore resource estimated to be in excess of 2500 TWh.

Status of the technology
A major achievement of the EU wind industry is that about 10 megawatt scale wind turbines are now commercially available. Cost trends show these latest megawatt machines as competitive although it is now pressing to address the limits of up-scaling and the need for new concepts for large offshore units. Gradual innovation has led to the emergence of variable speed and direct drive designs to complement the established Danish stall regulated concept with geared drive train.

Increased wind turbine reliability and the in-roads made into markets world wide mean the future for the technology is bright. The real benefits of the substantial investment made by the European Commission and the EU member states into research to improve the understanding of wind turbine behaviour, through careful modelling and measurement, is just starting to bear fruit. It must be carefully sustained and is set to play a major role in future technology development.

Status of European research and development
Extensive measurement and model validation activities have been made possible through funding provided by national and international research programmes such as the EU JOULE programme. Design tool development is ongoing in areas of wind field representation, rotor aerodynamics, computational fluid dynamics, aeroelasticity, aerofoil design, and aeroacoustics. There is also considerable potential for further development of wind farm design tools and hardware systems for wind farm management. Key research areas include, lightweight/flexible designs, rotor systems development, aerofoil design, blade materials development, direct drive systems, optimum unit sizing, grid integration, hostile sites, hybrid systems and multi-megawatt design. Harmonised international design standards are being achieved and are crucial to the continuing success of wind technology.

The next great leap for the wind energy industry will be in the area of offshore development. The potential for this technology is vast and it requires, and deserves sustained and substantial research and development support.

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1 INTRODUCTION

This volume summarises:

- the wind resource which is the basis of all wind energy developments
- state of the art of European technology
- research and development requirements

A Technical Appendix is provided giving a detailed background of the evolution of the technology. This comprises a historical perspective, the present technology, wind farming issues and regulatory matters.

This structure is intended to allow the reader to assess the future requirements of the technology without, necessarily, having to appreciate the historical perspective and the more detailed technical aspects of the industry.

2 RESOURCE

"Exploitation will not be limited by resource!"

In order to put wind energy technology in its proper context it is important to have at least an approximate estimate of wind energy's strategic potential. An approximate estimate of the resource is adequate because the potential, at least in its simplest form, is vast.

Most attempts at estimating this potential use the same basic steps:

1. Define the climatic and physical characteristics - average wind speed and areas where turbines can be placed
2. Estimate the space available for development from the results of (1)
3. Using current technology estimate the energy yield which can be derived.

Step (2) has a major influence on the final result and is very difficult to perform accurately. This point is well illustrated in the table below where the results of two studies are compared.

van Wijk and Coelingh [1] used a systematic, and rather more conservative, approach than Grubb and Meyer [2]. They considered that any land which had a mean wind speed greater than 5.1 m/s was potentially exploitable and they further assumed that only 4% of that land could be used as a result of practical and social constraints. A recent study undertaken in Germany, by the Bundesministerium fur Wirtschaft, has further underlined the importance of the assumptions used in such calculations. It has shown that if land with mean wind speeds of between 4 and 5 m/s is included then the technical potential in Germany alone increases to over 90 TWh/annum. None of these studies include the offshore potential which was estimated by Matthies and Garrad [3] to be in excess of 2 500 TWh/annum, in European waters alone.

Region	Grubb and Meyer [1] (TWh/annum)	Wijk and Coelingh [2] (TWh/annum)
Africa	10 600	-
Australia	3 000	1 638
North America	14 000	3 762
Latin America	5 400	-
Western Europe	480	520
Eastern Europe and CIS	10 600	-
Rest of Asia	4 900	-
Total OECD		6351
Approximate world total	50 000	20 000
World consumption of electricity in 1994	12 500 TWh/annum	
OECD consumption	6 351 TWh/annum	

Table 2.1 Regional wind energy potential and world-wide electricity consumption

It is instructive to follow Wijk and Coelingh's analysis further since they provide a detailed description of the resource in Europe. This is illustrated in the table overleaf which shows not only the technical potential but also the electricity consumption of each country. In this table the offshore potential already identified in Sweden and Denmark is also included. If it is further assumed that any national grid system could accommodate a 20% penetration of wind energy then a realistic potential can be calculated which is shown in the last column. Applying this limitation ignores the potential for exporting wind generated electricity which will be an important commodity in the future.

Country	1995 Electricity production (TWh/annum)	Technical wind potential Wijk and Coelingh (TWh/annum)	Realistic potential = lesser of 20% consumption and technical potential (TWh/annum)
Austria	60	3	3
Belgium	82	5	5
Denmark	31	27	6.2
Finland	66	7	7
France	491	85	85
Germany	534	24	24
UK	379	114	75.8
Greece	41	44	8.2
Ireland	17	44	3.4
Italy	207	69	41.4
Luxembourg	1	0	0
The Netherlands	89	7	7
Portugal	32	15	6.4
Spain	178	86	35.6
Sweden	176	58	35.2
Total EU	**2384**	**588**	**343.2**

Table 2.2 The European wind energy potential and electricity consumption

The message from this brief introduction to the wind energy potential is very clear - its exploitation will not be limited by the resource.

3 STATUS OF WIND TECHNOLOGY - SUMMARY

"... the future for the technology is bright!"

European wind technology is a great success story. In a matter of a decade and a half it has evolved from an industry making small, simple and sometimes unreliable machines into a technology which can compete with the well established conventional forms of power generation. It has volume production of medium size machines in the 600 kW range and some 10 designs in the megawatt range with commercial prospects. The increase in available rated capacity (by about a factor of 3 from 500 or 600 kW to 1.5 MW) is striking and has been a very rapid development since 1990. The arrival of the largest units is timely as the industry prepares for major offshore developments. This evolution is shown schematically in Figure 3.1.

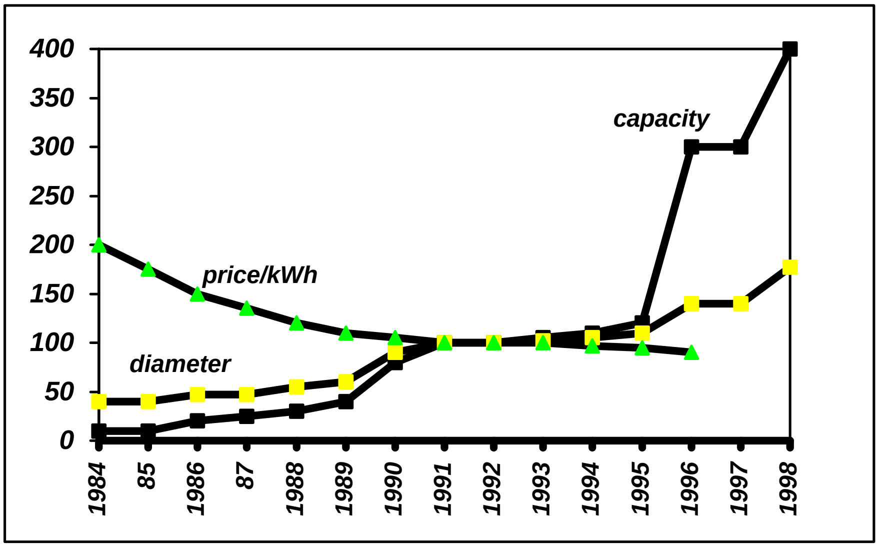

Figure 3.1 The development of commercial machines (1992 = 100% for all parameters)

To provide confidence to investors continued effort is required on standards and certification. This important area of work has been responsible for a steady improvement of both design and manufacturing quality and has helped the industry move from its early pioneering stage to a competitive industry which can compete on a world wide market. Continued efforts on this front are vital.

Design consolidation has taken place with three bladed designs predominating to an even greater extent than previously. There is increasing use of variable speed systems. A major recent innovation has been the introduction of direct drive generator technology.

Widespread exploitation of wind energy potential will require properly optimised machines for different types of site:

- high and low wind speed
- onshore and offshore
- remote and grid connected
- large and small applications

Cost trends show the latest megawatt machines as competitive although it is now pressing to address the limits of up-scaling and the need for new concepts for large offshore units. Major offshore developments are certain in the early part of the next century. This will be the next major step for the technology and will result in a dramatic increase in potential in particular in the northern European waters.

Careful consideration of the interaction between wind turbines and the grid is now, and will continue to be, an important area of both technical design and political action. This matter will come to the fore over the next decade as the substantial goals established for the industry are realised. It will require a radical re-think of the way grid management is organised on a Europe wide basis.

The increasing reliability of wind turbines and growing penetration of world wide markets mean the future for the technology is bright. The real benefits of the substantial investment made by the European Commission and the EU member states into research to improve the understanding of wind turbine behaviour, through careful modelling and measurement, is just starting to bear fruit. It must be carefully sustained and is set to play a major role in future technology development.

4 STATUS OF EUROPEAN WIND ENERGY R&D

"The next great leap for the wind energy industry will be in offshore development."

In this section the status of the different areas of technology are assessed and research and development requirements are identified.

4.1 Future design needs

4.1.1 Design tools

Over the last twenty years research workers have played a vital role in the development of mathematical models which can represent the behaviour of wind turbines. This work has involved extensive measurement and model validation activities and has been made possible through funding provided by national and international research programmes such as the EU JOULE programme.

As confidence in the mathematical models developed by research organisations has grown, there has been increasing interest from wind turbine manufacturers wishing to make use of such models as the basis of their design calculations, replacing the simplistic design approaches of the early days of the industry. It is therefore a challenge to the research community that they should now develop software tools which offer reliable models of wind turbine behaviour but also provide the quality, robustness and ease of use required by the designers. This process is well underway and there are already a number of computer programs which originate from European research and consultancy organisations and are now being used by manufacturers for design and certification of wind turbines.

There are several aspects of the methods currently used for the design calculation of wind turbine performance and loading which require further research and development effort:

Wind field representation

Further research is required to investigate suitable models of the wind characteristics experienced by wind turbines operating in the following situations:

- in wake flow within wind farms,
- on complex terrain sites,
- in different conditions of atmospheric stability .

An area of great importance and significant uncertainty is that of the modelling of extreme wind conditions. Current design standards are based on rather arbitrary deterministic descriptions of extreme wind events and there is an urgent need for the validation of this approach or its replacement with alternative, probabilistic methods.

Rotor aerodynamics
Although there has been extensive research in this area, the general understanding of the development of aerodynamic stall on a rotating wind turbine remains poor and the modelling of stall is considered to be the most significant inadequacy of current design calculation methods. The present uncertainty results in poor confidence in the design calculations of performance and loading for stall regulated wind turbines.

The development of models of steady and dynamic stall, reliable across a range of aerofoil sections and rotor configurations, requires the continuation of the major experimental and theoretical research programmes already underway in this area.

Computational fluid dynamics
Computational fluid dynamics tools are being developed in a wide range of engineering disciplines. Wind energy is only one area in which they can be used. There are still important aspects of wind energy technology which are not properly understood - the local flow over the blades and the flow of wind over complex terrain. Both will profit greatly from the application of CFD tools. Better understanding of wind flow and local air flow will yield major improvements in the confidence with which the technology can be applied and significant cost reductions will result.

Aeroelasticity
The current generation of wind turbine research codes and design tools has received very little validation against measurements from flexible machines. Further research effort will be required in this context leading to design tools which can be used to undertake reliable calculations of the coupled modal properties, aeroelastic stability and loading of wind turbines with flexible components exhibiting large deflections.

It is anticipated that with the continuation of relevant research programmes and the increasing power of computers, the sophistication and reliability of the design calculations undertaken by wind turbine manufacturers will continue to improve. This trend can only help to reduce unnecessary design conservatism and lead towards lower costs for wind generated electricity.

4.1.2 General R&D

In addition to the areas of research identified above, other areas requiring further research effort include:

- aerofoil design
- aeroacoustics
- verification and enhancement of design standards

- reliability analysis
- improvement of reliability of materials data
- design methods and assumptions for offshore wind turbines

Aerofoil development continues to be of importance, not because it is possible to get much more energy from wind turbine rotors but because tailoring of stall, management of loads and the structural implication of aerofoil size and shape can all contribute to more cost effective rotor blades and wind turbine systems.

There is also considerable potential for further development of wind farm design tools and hardware systems for wind farm management.

4.2 Wind turbine concept development

4.2.1 Lightweight/flexible designs

There is clear requirement for larger generating units, especially for offshore sites, where there may be greater freedom from some environmental constraints. High speed lightweight turbines may be considered. As has been discussed, the exploitation of structural flexibility to achieve weight and cost reduction is still more limited than may have been supposed. The development of composite hinges and other essentially "smart materials" developments may find increasing application in wind turbine systems. Optical fibres are already being evaluated for monitoring fatigue of blade structures.

4.2.2 High/low wind speed designs

The best wind resource in Europe, in the UK generally and in Scotland in particular, has been the latest to be exploited. This implies that feedback from the operation of European wind turbines on high wind speed sites has been quite limited and validation of designs for such sites is ongoing.

The general approach to high wind speed sites has been to offer a lower diameter in relation to power rating and conversely in low wind speed sites to offer increased rotor diameter. This is often done in a non-optimum but very expedient way using "hub extenders" - tubes inserted between the hub flange and blade root which increase overall rotor diameter. Tower height is also often increased on low wind speed sites.

It is, however, an oversimplification of the issue of coping with varying site conditions to consider it purely as a diameter/power rating adaptation. The differences in total design and cost implications of machines for high as opposed to low wind speed sites is substantial for genuinely optimised designs. As order books grow, more differentiated high wind speed and low wind speed designs may emerge.

4.3 Rotor systems development

4.3.1 Aerofoil design

Development of improved aerofoil sections for wind turbines has been ongoing. Low lift aerofoils with reduced roughness sensitivity and to shed maximum loads have been the focus of US developments [4]. In Sweden and the UK [5] high lift aerofoils have been designed which are suited to variable speed operation. LM Glasfiber have conducted many experiments with new aerofoils and also with new tip shapes designed to minimise tip sound.

Over recent years there has also been a move towards using higher camber NACA sections in an attempt to reduce rotor solidity. This, however, appears to have been accompanied by an increase in the likelihood of stall induced vibrations. The prevailing tendency among blade manufacturers is to use NACA 63 sections which may have in-house modifications in order to ease manufacture etc.

There is still considerable potential for rotor design optimisation and system load reduction (though not for much energy gain) through new aerofoil developments. Such developments will be very gradual. There are considerable overheads in changing blade tooling, some risk of unsatisfactory performance and time required for testing to develop confidence in new rotor designs.

4.3.2 Blade materials

The historical development of blade materials from metals to composites (natural and man-made) are discussed in Appendix Section 4.5. Much development of existing composite material components is ongoing in respect of suitability for manufacturing methods. There is interest in resin transfer moulding, in pre-pregs (cloths pre-impregnated with resin - as used by Vestas in both the spar and shell structures of their blades), different weaves of glass cloth that alter the structural characteristics and also the required resin content etc. In wood epoxy manufacture the range of usable woods is being further explored and there is ongoing demand for materials testing in support of materials innovation for cost reduction.

Interest in the use of materials which can be re-cycled is developing as is the use of natural fibres. The application of these techniques is particularly relevant to an environmentally friendly technology such as wind energy.

4.3.3 Control mechanisms (beyond stall/pitch)

There have been many experiments to improve stall regulation. Vortex generators are widely used by blade manufacturers and there is interest in using air jet vortex generators [6] as an active method of boundary layer control.

Research has suggested that partial span systems of pitch control provide a more responsive and better quality of power control than full span pitching and also may be more economic. Concern about sound emission has probably deterred many manufacturers from pursuing such systems. Smart materials [7] are available, relatively expensive at present, that may slowly find application in wind turbine rotors allowing the development of intelligent blades.

4.4 Direct drive designs

The advantage of direct-drive concepts is the omission of the gearbox, by utilising a generator that can operate at the rotational speed of the rotor. This has benefits in two separate areas:

- for small and very small turbines, where rotor rotational speed is relatively high anyway, with the aims of saving cost and achieving very low maintenance,
- for very large turbines, where rotational speeds are low and torques very high, principally to achieve cost reduction through a simplified integrated design.

4.4.1 Micro-turbines (< 3 kW)

These turbines are in the range 0 to 3 kW approximately, and are characterised by the almost exclusive use of direct drive permanent magnet generators (PMG) for battery charging. The market is for remote telecommunications, electric fences, domestic systems, nomadic peoples, leisure craft and caravans. Almost 90% of micro-turbines use PMG technology.

4.4.2 Small wind turbines (< 30 kW)

The benefits of direct drive are the expected low maintenance and high reliability. Capital cost and efficiency are less important. Wind turbines with direct drive generators of 2 to 10 kW rating have been developed by Bergey, Westwind, Proven and LMW. All use permanent magnet generators. There are of course several non-direct-drive wind turbines in this size range.

Several manufacturers have direct drive turbines in the design or prototype stages at ratings up to 50 kW. All use PMGs except for the Atlantic Orient Corporation (AOC) 20 kW design which uses a switched-reluctance generator.

AOC generators are current being laboratory tested. The switched reluctance generator is the simplest generator of all with only laminated iron on the rotor.

4.4.3 Large wind turbines

The perceived benefits of direct drive systems for large wind turbines are:

- lower cost than a gearbox system;
- reduced tower-head mass and nacelle length;
- efficiency savings of several percent.

It is as yet unclear if these benefits are being realised in present designs, but it is quite clear that the new technology is already on a par with conventional solutions.

Direct drive machines always take advantage of the opportunity for variable-speed operation allowed by the AC/DC/AC converter. Most direct drive systems would be difficult to implement in fixed-speed operation as they lack the compliance of induction machines. Turbines with direct drive systems range from 200 kW to 1.5 MW (production and prototype machines). Both permanent-magnet and wound-rotor designs are used. Current direct drive designs include;

- Enercon E30 (200 kW), E40 (500 kW) and E66 (1.5 MW): synchronous generator, wound rotor, concept proven through extensive operating experience.
- Lagerwey LW45/750 (750 kW) at prototype stage, synchronous generator, wound rotor.
- Genesys 600, Tacke TW1500: proposed machines, permanent magnet excitation rather than a wound rotor, and reduced generator diameter.
- Aeolus III (3 MW): proposed development of existing AEOLUS II wind turbine, not yet built, using permanent magnets.
- PMG designs (prototypes tested up to 120 kW): ferrite magnets, elegant modular design.

While it would appear optimistic to expect large mass or cost savings in large wind turbines purely by the introduction of a direct drive system, it is likely that in a fully integrated design (with common bearings for the generator rotor and wind turbine rotor) the simplification of design, provision of wide range variable speed and elimination of gearbox maintenance will all favour the continuing development of direct drive systems.

4.5 Multi-megawatt design

Although the wind industry has demonstrated the technical and commercial feasibility of units of about 1.5 MW, and larger wind turbines have been built, the present generation of megawatt machines may well be close to the economic limit of up-scaling. In some land based applications and in the offshore application especially, yet larger generating units are desirable.

Multi-rotor systems with a number of rotors on a single support structure are a possible route to units of 5 to 10 MW capacity for good economics with minimum innovation and development costs. Such systems have been under consideration for a long time and a few (very old) and a recent design of Lagerwey have been built. Recent research in the UK [8] and studies in the Netherlands [9], [10] over a number of years confirm interest in this concept.

It is apparent that there is considerable overlap in the issues of larger turbine design and design for offshore which is now discussed.

4.6 Offshore design

The next great leap for the wind energy industry will be in the area of offshore development. The potential for this technology is vast and it requires, and deserves sustained and substantial research and development support.

4.6.1 System concepts

Most European turbines operate with a blade tip speed less than 65 m/s principally in order to contain sound emission within acceptable limits. It has been recognised that if offshore wind turbines are remote from the coast and can be allowed increased sound emission, then there is considerable scope for reduction of the weight and cost of the turbines themselves. A tip speed of 100 m/s may be acceptable for offshore wind turbines.

As with sound, if there is some relaxation in concern about the near field visual effect for offshore wind farms, there is added potential for cost reduction in support structures and greater tolerance of more unusual design configurations that may have economic merit.

Thus the general view is that, if higher tip speeds can be exploited, the cost of the wind turbine component of the offshore system can be significantly reduced compared to land based designs. Obviously this is very desirable to help offset the increased costs of foundations and electrical transmission associated with offshore projects.

A key objective for the design of cost effective offshore wind turbines will be that inspection and maintenance requirements are reduced to a minimum. Design for high reliability will be an important priority with an emphasis on minimising long term operation and maintenance costs, possibly at the expense of a somewhat higher wind turbine capital cost.

4.6.2 Optimum unit sizes

The largest offshore wind farm in the world is the 17 MW Dronten wind farm (based on 600 kW units). This farm is, however, only offshore in the sense that it has its foundations in the water of an inland sea. According to various studies, larger machines of several MW need to be used to reduce generation costs.

Total array costs decrease by a factor of more than 2.5 for support structures for machines with rotor diameters in the range 50m to 100m [11]. The costs of electrical power collection and transmission are also significantly reduced. Offshore wind turbines will have minimum tower heights determined by extreme wave and tidal statistics. Having fewer maintenance points and fewer interconnection between turbines per wind farm of given capacity will favour large wind turbines. The requirement for larger units of generating capacity is clear and possible technology for this was discussed in Section 4.4 Appendix.

4.6.3 Design tools for offshore wind turbines

There are at present very few design tools available which are capable of dealing with the combined wind and wave loading experienced by offshore wind turbines [12], [13]. There is an increasingly urgent need to validate analytical methods capable of the prediction of the loading and dynamic behaviour of offshore wind turbines. With the growing interest in offshore wind power over the last decade, there is a need to provide the manufacturing industry with design tools which can deal reliably with the complexity of combined wind and wave loading. As prototype offshore wind turbines are installed it is important therefore that detailed measurement programmes are undertaken to provide the data necessary for such validation work.

4.6.4 The future deep water offshore resource

There have been a number of studies throughout Europe to investigate the feasibility of floating wind farms installed in deep water. Various concepts for floating systems have been considered. The FLOAT [14] study undertaken in the UK investigated the outline design and costing of an offshore wind farm with floating turbines for water depths up to 100 m. According to this study, however, the cost of the floating platform, the cost of moorings and of transmission to land would seem to clearly indicate that floating wind turbine systems would only be exploited (if at all) in a second generation of projects after systems on sea bed foundations are generally established.

4.7 Grid integration

In order to meet the EWEA and, indeed, the EC targets which have been established for wind energy in the EU large scale penetration of the European grids will be required. To date this problem has been addressed in only a very superficial way. Research is required to determine an economic means of exporting electricity from the remote, wind rich areas of Europe to the more central areas of high load. National and Europe wide system studies are required as well as continued work to provide a better understanding of the interaction of wind turbines and the electrical system.

4.8 Hostile sites

In this context "hostile" is used to describe sites with environmental characteristics outside the normal, conditions which are presently being commercially exploited. There is little experience to date of low temperature, high turbulence or very high wind speed sites. Such sites often exhibit both extreme loading conditions and high energy yield and hence an improved ability to exploit them will provide significant benefits.

4.9 Hybrid systems

There has been relatively little attention to date to the integration of wind energy with other renewables. Such applications will be at a smaller scale than most of the other areas identified in this report when taken individually but when considered in total their contribution is substantial. There is enormous scope for application of hybrid systems: wind-photo-voltaic, wind-biomass, wind-diesel and desalination. This market is vast and largely untapped. It also offers a means of bringing energy to some of the most deprived areas of the world in an environmentally friendly fashion.

4.10 Standards and certification

The development of a harmonised set of internationally recognised standards and certification procedures has proved to be of vital importance for the building of confidence in wind energy. This point is particularly germane to the establishment of good relations with the financial sector. The process is now firmly under way but requires continuous improvement and refinement to keep pace with new developments in the technology. Continued research and development on this front is therefore required.

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APPENDIX

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6 A TECHNOLOGY PERSPECTIVE

6.1 The challenge of wind technology

The concept of a wind driven rotor being used to provide mechanical power is ancient, with the earliest written reference to windmills [1] being from the 5th century BC. To generate electricity from the wind requires the connection of such a rotor to an electric generator. Even 20 years ago, the average household in the US possessed about 40 electric motors [2]. Hence, although the electric motor/ generator is not ancient it has been in mass production for several decades. This familiarity with the key elements of a wind turbine can generate an illusion (outside the industry) that the technology is undemanding - a false assumption which proved very expensive for some of the aerospace participants in the early 1980's. The challenge of modern wind technology, however, lies in producing cost effective technology that will:

- meet the specification of an electricity generating wind turbine,
- cope with the enormous variability of the wind.

6.2 The specification of a modern wind turbine

Traditional "Dutch" windmills had proliferated to the extent of about 100,000 throughout Europe at their peak usage. These machines were always attended and usually manually controlled. They were integrated within the community, designed for frequent replacement of certain components and efficiency was of little importance.

In contrast, the specification of a modern power generating wind turbine is to generate high quality, network frequency electricity. To meet economic targets, each wind turbine must function as an automatically controlled independent "mini-power station". It is unthinkable for a modern wind turbine to be permanently attended, and unacceptable for it to be much maintained. The development of the microprocessor has played a crucial role in realising this situation and thus in enabling cost effective wind technology. A modern wind turbine is thus required to work unattended, with low maintenance, continuously for in excess of 20 years.

6.3 The variability of the wind

The variability of the wind is a crucial factor in the exploitation of wind energy and in the design of a wind turbine. A typical northern European coastal site has a mean wind speed at 10m of 5 m/s and may expect extreme winds of 45 m/s. While neither the greatest recorded gust [3] of 103 m/s on Mount Washington in the Appalachians nor the highest recorded annual mean wind speed [3] of 18 m/s on a mountain margin of East Adelie Land, Antarctica are in exploitable wind resource areas, they illustrate the vast range of wind conditions that may be experienced. The variability of the wind is acknowledged in the design ranges of commercial wind turbines. It is common to offer tower height and rotor diameter variations around a particular core design to suit specific site conditions.

6.4 Development of design tools

A major development in the wind industry, particularly during the 1980's and directly related to the foregoing discussion of wind variability, has been the development of design methods that take adequate account of the nature of the wind and in particular the characteristics of atmospheric turbulence in the prediction of loads [4]. This process, made possible by the funding and execution of national and international research programmes, has influenced the associated development of design standards and has contributed to the high reliability and availability of modern wind turbines. It is now common practice for wind turbine designers to make use of sophisticated computer models and design tools, replacing the simplistic methods of the early days of the industry.

6.5 The unique aspects of wind technology

Wind turbines have little respect for engineering conventions: the blade aerofoils are often required to operate in stall, the power train components are subject to highly irregular loading inputs, and the number of fatigue cycles experienced by the major structural components can be orders of magnitude greater than for other rotating machines. By way of example, consider that the fatigue design life of a modern wind turbine amounts to about 13 years of unattended operation whereas that of a typical motor vehicle may be equivalent to about four months of manned operation.

Thus wind technology has a unique technical identity and unique R&D demands. This is very apparent in the patterns of European technology development and well recognised in R&D support for wind energy from the Fourth Framework programme of the European Commission.

6.6 A remarkable achievement

Over the last fifteen years wind turbines have grown dramatically in size. They now regularly achieve higher availability than conventional plant. The understanding of the science behind the technology has developed at the same pace and now it is possible to build reliable, cost effective machines with a lifetime of 20 years which are the size of a jumbo jet - a remarkable technical achievement.

7 RECENT HISTORY

7.1 Before 1970

The 53m diameter, 1.25 MW Smith Putnam wind turbine was erected at Grandpa's Knob in Vermont, USA in 1939. This design brought together some of the finest scientists and engineers of the time (aerodynamic design by von Karman, dynamic analysis by den Hartog) and the wind turbine operated successfully for longer than some megawatt machines of the 1980's. It was a landmark in technological development. The machine failed (losing a blade) because of a sub-standard site weld repair.

It was not restored due to wartime pressure on funds and an economic climate, in terms of fuel costs, that remained unfavourable for wind energy until the fuel crises of the 1970's. Valuable lessons about quality input to design, machine dynamics, fatigue, siting sensitivity etc. available from this project were largely forgotten and subsequently painfully re-learned, especially during the wind farm developments associated with the California tax credits.

The next milestone in wind turbine development was the Gedser wind turbine. With assistance from Marshall plan post war funding, a 200 kW, 24 m diameter wind turbine was installed during 1956-57 on the island of Gedser in the south east of Denmark. This machine operated from 1958 to 1967 with about 20% capacity factor.

In the early 1960's Professor Ulrich Hütter developed the 100 kW, 34 m Hütter-Allgaier wind turbine - a 2 bladed, teetered rotor with a high tip speed. Hütter's ideas for high speed flexible design had a major influence on wind turbine research in Germany and further afield.

7.2 1970-1987

These three machines represent the beginnings of three different facets of wind turbine development: the megawatt machines which are only now appearing on the commercial scene, the Danish style commercial machines that have dominated the market for the past 15 years and a glimpse of further lightweight machines still largely unrealised.

The Gedser machine, a simple rugged design with a tubular tower, 3 blades and tip brakes, had all the ingredients of the later mainstream Danish designs. It was refurbished in 1977, instrumented and operated as a test machine providing a research basis for the development of modern Danish wind technology.

In the early 1980's, many issues of rotor blade technology were investigated. Steel rotors were tried but rejected as too heavy, aluminium as too uncertain in the context of fatigue endurance, and the wood-epoxy system developed by Gougeon Brothers in the US was employed in a number of small and large wind turbines. The blade manufacturing industry has, however, been dominated by fibreglass polyester construction which evolved from a boat building background and became thoroughly consolidated in Denmark in the 1980's.

In the US, following the National Energy Act of 1978 which incorporated the Public Utilities Regulatory Policies Act (PURPA), a market was guaranteed for independently produced electricity. By 1980 a combination of state and federal, energy and investment tax credits was providing a total tax credit approaching 50% and this initiated the California wind boom. Over the period 1980 - 1995 about 1700 MW of wind capacity was installed, more than half after 1985 when the tax credits had reduced to about 15%.

The tax credits attracted much valid criticism as a market stimulation mechanism, which, initially at least, caused an indiscriminate overpopulation of various areas of California (San Gorgonio, Tehachapi and Altamont Pass) with wind turbines many of which were ill-designed and functioned poorly if at all. However, in the backlash to the early unsatisfactory developments, the tax credits offered a major export opportunity to European and especially to Danish wind turbine manufacturers who had relatively cost effective, tried and tested hardware available. The technically successful operation of the later better designed wind turbines in California did much to establish world-wide credibility for wind energy.

The Californian market caused bankruptcy as well as commercial success for many European and US companies. Nevertheless it has contributed enormously to the development of the modern European wind industry. The technology impact has been in two main ways, most importantly for mainstream Danish suppliers was the existence of a sizeable market enabling the development of manufacturing methods, component cost reduction and improved functionality. Secondly, the design diversity has been valuable for informing future technology developments such as interest in lightweight and flexible components.

In the operational experience of the Californian wind farms, serious problems with blade root connection, under-performance due to fouling of blade aerofoil sections, damage to yaw systems due to extreme and poorly understood atmospheric turbulence, premature fatigue of high speed shaft braking systems etc. were among many problems encountered and gradually solved in the progress of the technology.

7.3 1987-present

The growth of wind energy in California was not sustained or paralleled elsewhere in the US and more recently electricity deregulation has created much uncertainty as to how wind energy in the US will move forward and only now in 1997 is the US market starting to re-emerge.

In contrast, there has been striking development in the northern European markets with installation in Germany of around 200 MW per annum in the early 1990's. Three factors have contributed to that boom a subsidy for research and development, a buyback policy similar to that in Denmark and high utility rates. From a technological stand point, the significant outcome was the development of new German manufacturers and of some new concepts: the introduction of innovative direct drive generator technology, is noteworthy.

Although there have been gradual and significant new technology developments in direct drive power trains, in variable speed electrical and control systems, in alternative blade materials and in other areas, perhaps the most striking trend in recent years has been the development of ever larger wind turbines leading to the current pre-commercial generation of machines with ratings in the megawatt range. This trend is discussed in Section 4.

8 DESIGN STYLES

8.1 Horizontal and vertical axis

A great variety of vertical axis designs has been developed. These include the troposkein shape "egg-beater" wind turbine (named after its inventor, Darrieus and developed in the 1980's by the Flowind Corporation especially), the "H" shaped design with straight blades developed by Musgrove in the UK (later adopted in a direct drive design of Heidelberg Motor), and a considerable number of variants some with ducted or shrouded stator vanes surrounding the rotor and some based on the Savonius design or the gyromill concept.

Vertical axis designs have an advantage of rotational symmetry that obviates any need for a yaw system. It was often a claimed advantage that all the drive train and power conversion equipment can be at ground level, but it was found that this implied a long and heavy torque tube for the main shaft and various designs compromised with gearboxes at the top of the main shaft. The overriding disadvantages, however, of the vertical axis design compared to horizontal axis are:

- inherently lower aerodynamic efficiency because the drive torque varies strongly with blade position in the rotor circle (and may even be negative in some positions),
- substantial passive support structure in the rotor system with an associated cost penalty.

While judgement on many design options in wind turbine technology has been deferred, there is now an overwhelming vote in favour of horizontal axis design.

8.2 Number of blades

Basic aerodynamic principles of rotor design determine that a rotor designed for a given rotational speed has an optimum total installed blade area that is a fixed proportion of the rotor swept area and varies inversely with the chosen rotational speed. There is a small aerodynamic advantage in having many slender blades rather than a few wide ones to make up the required blade area. The aerodynamic tip loss at the end of the blades is thereby minimised. The associated energy penalty for a 1 bladed rotor compared with a 3 bladed rotor is about 10%, and for a 2 bladed rotor compared with 3, about 4%.

The single bladed rotor requires to be hinged with a counter balance and is not lighter than a 2 bladed rotor. The 2 bladed rotor, although in better shape dynamically than a single bladed rotor, must accept very high cyclic loading if a rigid rotor hub system is employed or provide a so called teeter bearing to allow the rotor blades to rock (as a pair) to alleviate blade, drive train and tower head loading. Such teetered rotor designs can reduce fatigue loading much of the time but have to cope with occasional teeter impact load cases which are often design drivers. The three bladed rotor is simpler dynamically and, as has been mentioned, a little more efficient aerodynamically.

If 1, 2 or 3 bladed rotors are designed for similar tip speeds (as they have not been in the past but would require to be in the future for European land based applications subject to current sound limits) then the rotor blades of the 3 bladed rotor are more highly stressed than for the 2 or 1 bladed system and thus rotor blade costs will be higher for the 3 bladed system. Of course, it is the overall effect on wind turbine cost effectiveness (energy capture/capital cost) that really matters and that is only determined with a view of the complete design. Determination of optimum design configurations has been researched in depth [5] in studies supported by the European Commission.

Table 3.2.1 illustrates the relative proportion of 1, 2 and 3 bladed designs among present commercially available wind turbines of over 30 kW rated output. If the data were presented as the proportion of operational machines the dominance of the 3-bladed designs would be still more pronounced.

Number of blades	% of designs
1	2
2	24
3	74

Table 3.2.1 Blade numbers of commercial wind turbine designs

A major factor in the current prevalence of 3 bladed rotors has been the historical connection to the earliest (3 bladed) Danish designs and the associated need for a dynamically simple rotor in the development of stall regulation. A further major factor in the present European market is a common perception among the general public and planning authorities that only 3 bladed designs have a harmonious visual impact. Although this is clearly a subjective view it is equally clearly a dominant one.

8.3 Pitch or stall control

The issue of pitch or stall control mainly arises as a highly polarised debate in the design of medium and large wind turbines. With small turbines more options are available.

Stall regulation does not deal with the latter issue whereas pitch regulation deals with both but at the expense of the pitch system mechanisms and the associated control.

In pitch regulation (except when blades are sometimes pitched back into stall in a design option often described as “active stall”) the blades regulate power delivered by the rotor by pitching the blades to reduce the lifting forces generated by the blade aerofoil sections. The essence of stall regulation is that, without any change of rotor geometry, the rotor aerofoils stall as wind speed and relative flow angle increase. Power is regulated by the progressive loss of rotor efficiency as stall extends over the rotor.
For such stalling to take place it is essential to hold the rotor speed constant, and this is usually effected by an asynchronous generator connected to the electrical network.

8.3.1 Small wind turbines (< 30 kW)

There are a variety of methods used to provide power and speed regulation of small wind turbines. These include (Figure 3.3.1);

- “no control” in which the turbine rotor and system is designed to cope with whatever extreme speeds may result on no load (perhaps with some deformation of the blades under centrifugal force helping to degrade aerodynamic performance and reduce ultimate speed),

- "yaw" and "tilt" in which the rotor axis is moved out of the wind direction (often effected by an offset between the centre of rotor thrust and the yaw or tilt bearings),
- "pitch" and "stall" as in large wind turbines.

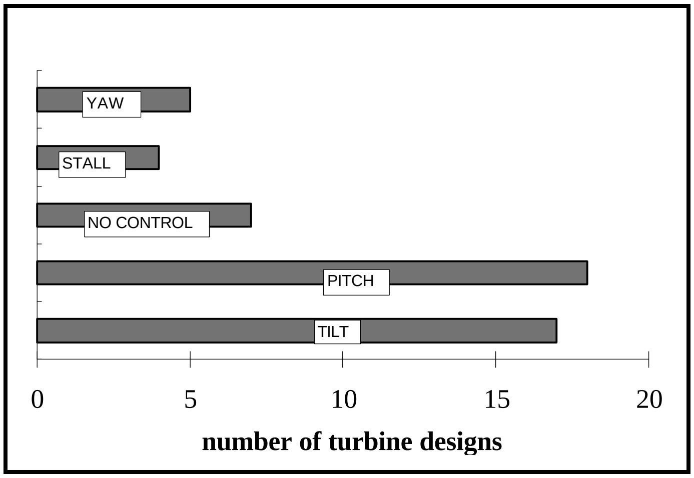

Figure 3.3.1 Speed control of small wind turbines

It is difficult to avoid misrepresentation in distinguishing between power control, speed control and overspeed regulation of small wind turbines. Most of the turbines using "yaw", "tilt" or "no control" exploit stall effects. Nevertheless Figure 3.3.1 gives an accurate impression of the occurrence of mechanisms to effect pitching, yawing, tilt etc. for safety or load regulation functions. The issue in small machine design is whether simple minimalist and passive systems can be made to work well enough, or active pitching mechanisms similar to larger machines must be employed.

8.3.2 Large wind turbines

The main issues in choosing between pitch and stall regulation are listed in Table 3.3.2.

Issues	Pitch	Stall
Energy capture	better in principle	compromised power curve
Control with fixed speed	difficult in high wind speeds	generally satisfactory, although design uncertain
Control with variable speed	better power quality, lower drive train loads than any stall option	requires proving
Safety	can be a complete rotor protection	needs auxiliary systems for overspeed protection
Cost	more cost in rotor systems	less cost in rotor, but more in braking system

Table 3.3.2 Pitch v stall issues

Large wind turbines almost exclusively use pitch or stall control. In a few instances, yawing out of wind is used as a back up safety procedure or as contributory to control. Recently, some manufacturers have used stall in conjunction with variable speed operation. The one configuration which has now been unanimously rejected is fixed speed pitch control. This combination produced very large transients in the power output when controlling power. This rejection is, however, rather interesting since it was, in the early days, a popular choice.

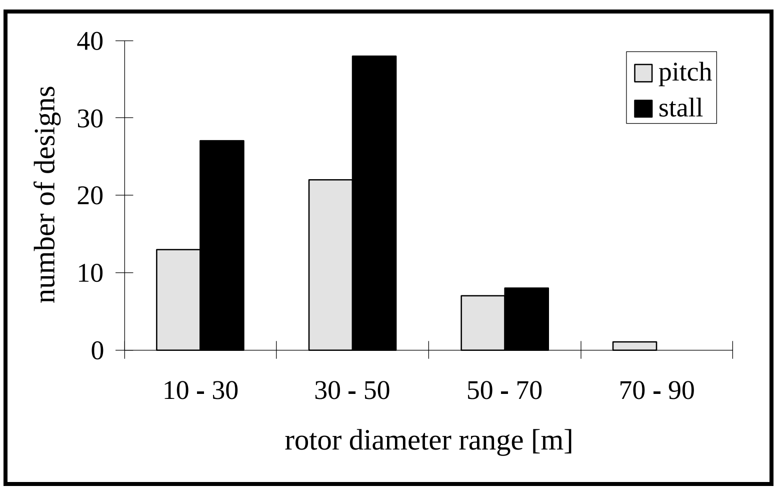

Figure 3.3.2 Pitch or stall control

Whereas there is still an overall dominance of stall regulation (about 60% of designs) as a design choice, the proportion of pitch and stall control in megawatt machines is almost equal. In the German market especially, large wind turbines are favouring the employment of “independent” pitching systems in which each blade has independent pitch actuators. This is because the pitch system then provides two independent rotor brakes. Even with one blade stuck at fine pitch in a fault condition, the other two can operate to bring the rotor to safe speed. This independent pitch system is distinguished from the previously more common “collective” pitch systems in which the pitching of all three blades is mechanically interlinked and powered by a single actuator.

Concern about power quality of stall regulated machines (also especially in the German market) has deterred some manufacturers who supply medium size stall regulated machines from continuing this design feature in their megawatt designs. There has also been concern over a number of years about stall induced vibrations [6], especially in the context of larger machines, and it is a significant vote of confidence that many manufacturers of the megawatt scale machines have adhered to stall regulation.

Increased interest in variable speed coupled with the uncertainty about how variable speed stall control machines will operate has however reduced the interest in stall machines at large scale.

8.4 Variable speed design

8.4.1 Motives for variable speed operation

There has been long standing interest in variable speed design for a number of reasons;

- the “traditional” expectation that higher rotor efficiency and more energy can be extracted compared to fixed speed operation,
- the increased attention given to sound in the modern European market and the ability of a variable speed system to reduce speed and sound in light winds while affording a relatively high top speed avoiding too much torque and cost in the drive train,
- the capability of variable speed operation to ease pitch control, improve power quality and alleviate drive train loads (thereby possibly reducing the design requirements, and cost of the gearbox or generator).

8.4.2 Nature of variable speed systems

To maximise the benefits listed above, a wide range of variable speed is required (about a factor of 2.5 to 3 in speed variation). There are many ways of providing variable speed. Mechanical systems do exist, but electrical systems predominate. A variety of compromise solutions which provide some but not all of the benefits of wide range variable speed are in use. Collectively these options are much more common than wide range variable speed.

They comprise:

- two speed systems,

- a variety of continuously variable speed systems where, at the cost of reduced overall speed range, only part of the output is passed through the variable speed drive and power conditioning equipment.

In Danish designs of 10 years ago it was commonplace to achieve two speeds by switching between two generators connected by a belt drive. Present generation wind turbines almost exclusively use pole switching on a single generator to achieve two speed operation. Figure 3.4.2 shows the distribution of some of these design options among present commercial wind turbine designs.

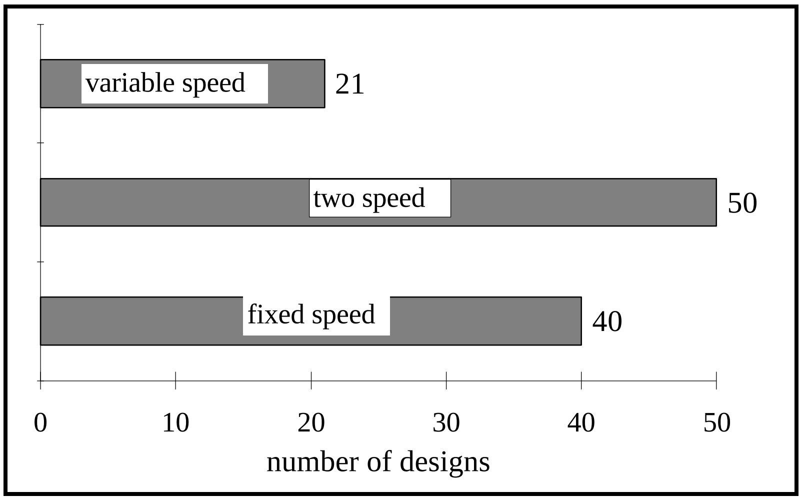

Figure 3.4.2 Design choice in type of speed operation

Among the continuously variable speed operation designs, only about 1/3 of designs employ a wide range of variable speed (speed range > 2.5:1). The majority trade speed range and performance with the cost of power conditioning systems. In the Vestas OptiSlip system, limited variable speed (10% speed variation in operation at rated power) is used to give excellent power quality. Many manufacturer's design studies have favoured the two speed system as most economic (as is reflected in Figure 3.4.1). The current emphasis on the development of direct drive systems which in general best suit variable speed operation, and the associated development and cost reduction of power conditioning systems will in all probability result in increasing future use of wide range variable speed in wind turbine design.

8.5 Status of light weight and flexible designs

There has always been interest in light weight and structurally flexible machines (blades and towers especially) as a route to lower cost technology. There is a tendency to regard the terms light weight and flexible as being intrinsically related.

While it is clearly the intention in structurally flexible design to shed loads, use less material and hence achieve light weight and reduced cost, many existing light weight machines are structurally stiff rather than flexible. In designs with significantly flexible blades or towers such as the Carter wind turbine, structural flexibility may well have merit but has less to do with achieving low weight than having a low drive train torque through the choice of a high design tip speed. To date these concepts have not met with commercial success.

The latest design of this type is the Wind Energy Group WEG MS4, a 600 kW, 3 bladed, free yaw, downwind turbine, incorporating a nodding nacelle and the special development of structurally flexible blades with high strain capability. Significant load shedding in extreme winds is obtained from the flexible rotor blades. The self-erect system for this design is particularly elegant. The design concept of this machine runs counter to that adopted by some other European manufacturers. However, elements of flexibility have also appeared in the recent Vestas V-47 machine which uses flexible blades to allow a substantially larger rotor to be fitted to a support structure which is almost identical to the smaller V-42 and V-44 machines.

Again in considering rotor blades in general, those manufactured in the materials of highest fatigue strength to weight ratio (wood epoxy and the CFRP blades of Atout Vent especially) are the lightest but also the most stiff. This underlines the fact that there is no direct association of light weight and structural flexibility.

These comments are not intended to undervalue the potential usefulness of structural flexibility both in relieving loads and in replacing active mechanisms. The conclusion is rather that the light weight wind turbines of the present generation achieve their light weight not primarily via structural flexibility, and the greatest impact of structural flexibility in wind turbine design is yet to come. Plastic and composite hinges (already employed in small machines), flexbeams and smart materials have much potential for future developments (Section 4.5.1). Very soft towers (i.e. towers with a natural frequency below rotor frequency) have been employed in wind turbine designs. Care is required with system dynamics but such designs can result in reduced tower mass and cost.

9 PRESENT TECHNOLOGIES

9.1 Small wind turbines (<1kW - 30 kW)

There are presently two billion people without electricity supply in the world. To satisfy the entire rural demand, full electrification with grid-extension would cost more than 1 trillion ECU. The market for small wind turbines includes a diversity of applications for turbines over a range in rating up to 50 kW. A great expansion of this market [8] is forecast.

Application	1995 MECU/year	2005 MECU/year
Remote Homes	4	100
Telecommunications	2	20
Village/ Rural Electrification	3	400
Miscellaneous Remote Site Loads	2	20
Potable and Irrigation Water Pumping	1	100
Oil Well Pumping	0.1	30
Refrigeration	0.1	5
Desalination	0.1	5
Total	**12.3**	**680**

Table 4.1.1 World market for small wind turbines

There is an increasing number of small companies supplying small turbines. Small wind turbine designs are also being produced by two major manufacturers of large wind turbines, Enercon and *Micon , and there is significant international competition, for example, designs from the United States such as Windlite 8 kW; World Power Technologies 22 kW; Cannon/Wind Eagle 35 kW and Bergey Windpower 40 kW.

The 10-50 kW rating range, in which the modern Danish and European wind energy business started, is now an important market sector. There is a growing perception that this market may be best served, not by exploiting the existing design concepts which have been transferred to larger designs, but by adaptation of design concepts common in yet smaller turbines. Such concepts include Permanent Magnet Generator (PMG) direct drive generators for low maintenance and good efficiency, and passive pitching or yawing for protection of the rotor. In this connection, the technology of the Proven Engineering 2.2 kW design is notable as it combines a direct drive PMG generator with a self regulating rotor. The table overleaf lists current European manufacturers of small wind turbines in the 10 to 50 kW range. Most are for both grid connected and stand alone applications.

* Micon A/S and Nordtank Energy Group A/S merged into the new company NEG Micon A/S on July 4 1997.

Manufacturer	Rating (kW)
Aeroman	33
Aeroturbine	9
Atlantic Orient Corp 15/50	50
Enercon E12	30
Fuhrlander 30	30
Genvind	22
Jacobs	10,20
Husumer Schiffswerft -HSW 30	30
JBA Vindenergi	15
Lagerwey 18/80	80
LMW	10
SudWind S12	30,37,45
Vergnet	2,3,5,10,15,25, 50,60

Table 4.1.2 Power ratings of small wind turbines

There is great design diversity among small wind turbines partly due to a wide range of applications. Figure 4.1.1 shows the vast range in design tip speed which is very much at odds with the larger machines for which there is a high degree of uniformity.

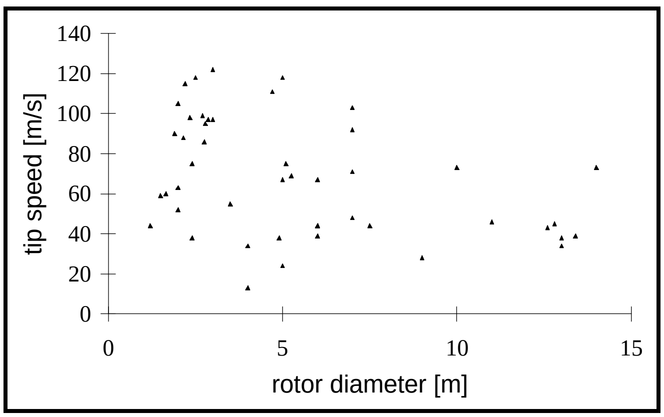

Figure 4.1.1 Design tip speeds of small wind turbines

The lowest tip speeds relate to a few high torque pump designs (the Brummer 1kW, 4m diameter, 7 bladed wind pump has a tip speed of 13 m/s). The highest tip speeds reflect the desire to have a low torque, low cost system in markets where there may not be the same problems with sound as with the larger turbines. Some manufacturers design small rotors to tolerate extreme overspeeds (e.g. the Bergey 10 kW, 7 m diameter wind turbine operates up to a tip speed of 220 m/s) so as to avoid the cost of regulating systems. Figure 3.3.1 illustrated how common it is to employ tilt or yaw control to limit rotor loading and rotor speed. This is usually achieved in an arrangement where the rotor thrust provides the actuating moment.

The aerodynamic performance of small wind turbines (even market leaders) is often relatively poor. For example, the Bergey 10 kW compared to the Bonus 600/41 has a similar power curve when normalised to power rating. However the productivity of the rotors is 260 W/m^2 (Bergey) compared to 455W/m^2 (Bonus). This is not unusual in small machines, and in part the much increased cost/kW of small machines is attributable to a strategy of increased rotor diameter being used to compensate for shortcomings in aerodynamic design.

The reason for this poorer performance is, to some extent, attributed to reduced efficiency in operation at low Reynolds Number or to inappropriate aerofoil selection. Sometimes, however, it results from undue compromise in blade design and construction (in the interest of cheap blades and low first cost) or because of the use of very crude power regulation systems. There would appear to be a significant opportunity for European manufacturers to undertake special technology developments that may produce a highly competitive design for a fast growing world market.

Among the smallest wind turbine sizes, the success of the Rutland designs of Marlec Engineering is remarkable. These battery charging units range from 20 to 250 W in rated output. Over 30,000 machines in this design range have been supplied.

9.2 Medium size wind turbines (30 -600 kW)

The distribution of medium and large machines in numbers and in capacity (Figures 4.2.1 and 4.2.2) includes a major recent growth in the supply of units rated around 500-600 kW and shows the dominance of this size range in terms of world-wide installed capacity.

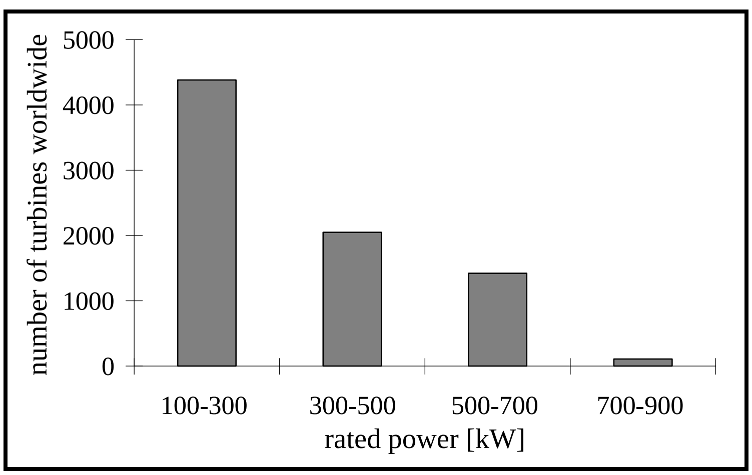

Figure 4.2.1 Numbers of wind turbines in various ranges of rated power

Medium size wind turbine technology has matured with some manufacturers in very steady production of 600 kW wind turbines. The terminology has chased the technology in a revealing way. Ten years ago no one would have classified 600 kW wind turbines as “medium scale”.

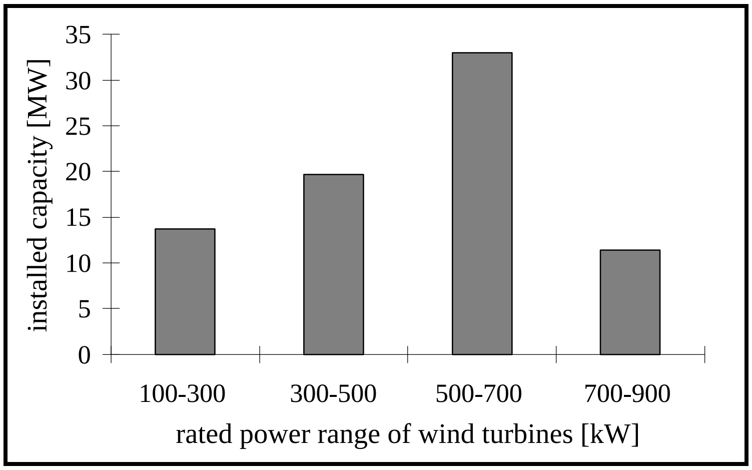

Figure 4.2.2 Installed capacity of wind turbines in various power ranges

Turbine configurations have stabilised with a predominance of 3 bladed stall regulated designs as has existed for some time among the smaller medium size turbines rated around 300 kW. Many yaw systems now use friction pads in place of rolling element bearings. Soft start electronics and pole switching generators are commonplace. Sound reduction has figured increasingly in wind turbine design. Spheroidal graphite iron castings with better acoustic damping characteristics than steel, elastomeric gaskets to reduced sound transmission are all common features. Visual impact influences most designs to some degree - strongly in respect of having caused a few manufacturers to switch from 2 bladed to 3 bladed design and more moderately in determining paint colours and in avoidance of unsightly features. Some manufacturers paint the tower base with grades of green/brown in imitation of the natural surroundings, reverting to white at a height of a few metres. Nordtank have employed industrial designers to determine the optimum nacelle shape in consideration of cost and visual impact.

A number of design adaptations have appeared as the world market for European wind turbines has grown. These include large diameter options for low wind speed sites (India especially) and low temperature designs for arctic climates. The technology of medium size machines is now quite mature and has in the main achieved that state by incremental rather than radical developments.

9.3 Megawatt scale designs

Although, world-wide, there was a number of megawatt scale designs in the 1980's, none of these has been replicated as commercial technology. It is a major achievement of the European wind industry, much supported by the WEGA programme of the European Commission, that the following manufacturers have megawatt scale wind turbines available, generally in a testing and proving state, but in a number of cases forming part of their current order book. Enercon [9] expect to install between 20 and 30, E66 1.5 MW wind turbines this year.

DESIGN TYPE	Rotor dia. [m]	Blade No.	Hub height [m]	Rated power [kW]	Tip speed [m/s]	Control Stall	Control Pitch	Speed
NEDWIND NW 53/2/1000-240	52.6	2	70	1000	68	✓		2-speed
NORDIC 1000	53.0	2	58	1000	69	✓		2-speed
BONUS 1 MW/54	54.0	3	60	1000	62	✓		2-speed
MICON M2300-1000/250 kW	54.0	3	59	1000	59	✓		2-speed
NORDEX N 54	54.0	3	70	1000	62	✓		2-speed
NEDWIND NW55/2/1000-240	55.0	2	70	1000	71	✓		2-speed
HSW 1000/57	57.0	3	70	1050	68		✓	2-speed
NORDTANK 1500/60	60.0	3	68	1500	60	✓		fixed speed
AUTOFLUG 1200	61.0	2	60	1200	66		✓	2-speed
VESTAS V63-1.5 MW	63.0	3	60	1500	69		✓	variable(10%)
TACKE TW 1.5	65.0	3	80	1500	68		✓	variable(1.4:1)
ENERCON - 66	66.0	3	100	1500	70		✓	variable(2.5:1)
KVAERNER WTS 80	80.5	2	80	3000	88		✓	variable 1.5:1)

Table 4.3.1 Current megawatt scale wind turbines

The Enercon E-66 is notable as the first megawatt scale wind turbine employing a direct drive generator (based on an up-scaling of technology successfully employed in the E-40 design). Only Nordtank have adhered to fixed speed stall regulated operation in the traditional style of smaller Danish wind turbines, and only Enercon have adopted what may be described as wide range variable speed. The price of Nordtank’s fixed speed decision is to have the lowest tip speed and highest specific drive train torque. The benefit as always is in simplicity. The vital quality of cost of energy will only emerge with time.

All other manufacturers have adopted some degree of speed variation. This is either for reasons of sound and energy capture in low winds (the two-speed systems especially) or to improve pitch control and power quality in high winds. Tacke Windtechnik achieve a 1.4:1 speed range using a doubly fed induction generator so that the power conditioning equipment is not rated for full power capacity thereby allowing some cost saving. There would appear to be a consensus that wide range variable speed is not worth paying for unless it comes as an integral part of a direct drive generator design.

There are cost and engineering difficulties with tip brakes for very large wind turbines and Bonus, whilst maintaining fixed pitch stall regulation for normal operation, prefer full span pitching into stall for rotor braking and overspeed protection.

The largest machine, the Kvaerner Turbine B MW design, is the result of a sustained interest in Sweden in developing large machine technology. In 1983 two 2 MW machines were erected at Nasudden and Maglarp. Development of a second generation took place from 1988 resulting in Swedish-German co-operation in a Nasudden II programme.
The resulting 3MW, 80 m diameter turbines, Nasudden II and Aeolus II, have operated for 3 years surpassing target availability and achieving significant reduction in

maintenance needs. Nevertheless, Kvaerner consider the present designs to be too expensive for commercial exploitation. Further developments are discussed in Section 4.5 (Volume 1)

9.4 Offshore

The next major development in the European wind industry is expected to be in achieving significant exploitation of the offshore resource. Development in support of this has taken place in areas of:

- better estimation of the offshore wind resource and improved methodology for wind modelling
- development of design methods for dealing with the effects of combined wind and wave loading,
- corresponding development of certification rules
- installation of pilot plant wind farms in shallow waters to evaluate machine marinisation, maintenance issues and cost of energy.

Recent pilot installations comprise:

Location	Capacity	Turbines	Utility	Date installed
Vindeby	5 MW	11 Bonus 450 kW	Elkraft	1991
Lely, Ijsselmeer	2 MW	4 NedWind 500 kW	ENW	1994
Tuno Knob, Jutland	5 MW	10 Vestas V39 500	Midkraft	1995
Dronten, Ijsselmeer	17 MW	28 Nordtank 600 kW	ENW	1997

Table 4.4.1 European offshore installations

The first serious commercial offshore wind farm was the Vindeby Offshore Wind Farm built by the Danish utility, ELKRAFT using 11 BONUS 450 kW wind turbines and reported by Bonus to have costed 77 million DKK. The turbines are sited 1.5 to 3 km offshore in shallow water ranging from 2.5 to 5.1 m depth. Each turbine has a broad based conical foundation weighing 1050 tons in total (of which about half was gravel and sand ballast).

Bonus had no intention to produce a special turbine design for maximum cost benefit in offshore operation. The aim was to use standard wind technology but establish what additional marinisation of the equipment was necessary for the continued survival of the turbines. Two dehumidifiers, two additional small service cranes, a special cooling system and special paint for the towers were the main items introduced specifically on account of the offshore environment. This confirms a general view that, especially as many land based turbines are specified for a coastal environment with salt spray in the atmosphere, the additional impact on the turbine system of marinisation for offshore operation is small.
A more significant issue, however, was difficulty in all but very calm sea states in using the turbine mooring systems during maintenance visits.

The small wind farm in the Ijsselmeer near Medemblik of 3 Nedwind 500 kW wind turbines was commissioned in June 1994. Some analysis of dynamic behaviour of the turbines has been undertaken and also some performance measurements have been made which indicate an improvement of about 30% in energy capture compared with land based sites. Interesting technical features include a wind farm Electrical Storm Identification Device (ESID) which instructs the turbines to park with their (2) blades horizontal reducing risk of lightning strike during the passage of a thunderstorm. A fog detection device operates to park the rotor and switch on warning lights for the safety of shipping.

In October 1995, the 10 Vestas V39-500 kW wind turbines installed by MIDKRAFT at Tuno Knob were operational. They are located in 5m water depth at 6 km offshore using box caisson foundations each of 1000 tonne. Much attention was given to environmental issues including a bird life study, visual impact assessment and other aspects including marine archaeology. After six months operation the cost of energy production was estimated as about 40% higher than for on-shore generation.

The latest and largest development is at a site on the eastern border of the Ijsselmeer near Dronten where 28 Nordtank 600 kW turbines are being installed on steel monopile foundations very similar to the Lely installation. The turbines are only 40 m offshore in a water depth of 5 m with access by pedestrian bridges.

In the present state of offshore technology, the turbines above the height of wave impact are little different from land based ones. The potential benefit from custom designed offshore wind systems of large unit output than present wind turbines is considerable and is discussed in Section 4.6 (Volume 1). Offshore wind energy has hardly started its evolution. It will be one of the most exciting areas of activity in the early years of the next century. There are clear signs that this development is underway - most manufacturers and major developers are already actively exploring the technology.

9.5 Rotor blade technology

With large wind turbine rotors of up to 66m diameter now in commercial production for megawatt scale wind turbines, and rotors of up to 100m diameter (Growian, MOD 5B) having been operated, a rotor blade technology has developed which is quite unique to the wind industry. Its evolution and status are now discussed.

9.5.1 Blade materials and manufacture

In Table 4.5.1 a summary is provided of the principal blade materials used and the numbers of each sold.

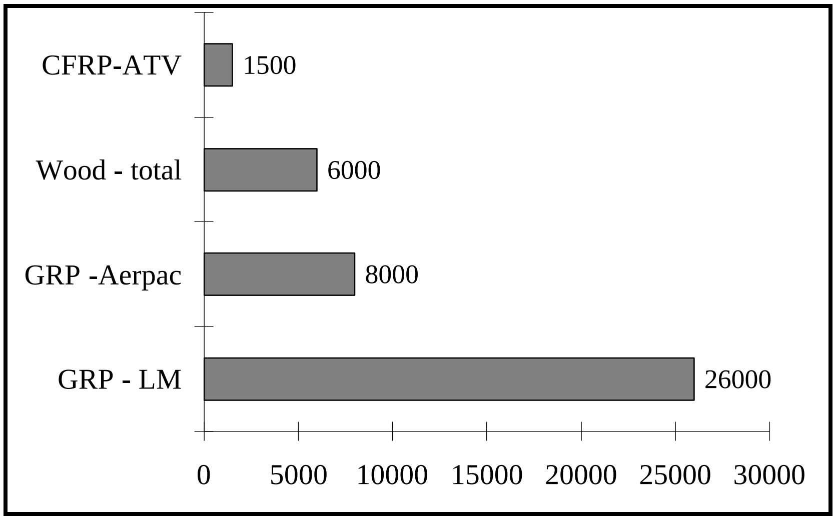

Figure 4.5.1 Principal blade materials and numbers sold

After early experiments with steel (too much self weight loading) and aluminium (uncertain fatigue endurance), the world wind turbine blade market is now totally based on composite construction. Glass reinforced plastic (GRP) comprising glass fibres of various qualities and polyester resin is by far the most common system. The use of GRP derives from boat building experience and commonly involves wet lay up and hand lamination techniques that are inexpensive but have restricted potential to be highly automated. The world leading blade manufacturer LM Glasfiber supplied blades to 50% of the world installed turbine capacity in 1995. Aerpac (Netherlands) are now evidently a leading manufacturer. Other main European manufacturers include Rotorline, (Netherlands), Polymarin (Netherlands), Abeking and Rasmussen (Germany), all predominantly involved in glass fibre based blade design and manufacture.

Wood is a logical material having the main fibres aligned uni-directionally. Being custom designed for resisting wind loads in bending, wood has excellent fatigue strength and stiffness characteristics. The critical factor in using wood in modern wind turbine blades was the evolution of an epoxy resin system (with suitable low viscosity for laminating) that would seal the wood laminates preventing significant moisture change during the design life.

The resin system was initially developed by Gougeon Brothers in Michigan who supplied many blades to the US wind turbine market in California. In the past few years Taywood Aerolaminates (TAL), who connect technically to the UK developments of the early 1980's, have made sales of wood epoxy blades to the international market.

Carbon Fibre Reinforced Plastic (CFRP) blades are a very recent development. It had been assumed that this material system was strictly for aerospace applications and too expensive for wind turbines. However, using "smart" production techniques, the French company, ATV Enterprise have produced cost effective wind turbine blades.

Composite is the key word in blade materials. The “wooden” blades of TAL have foam glass construction over the trailing edge 40% of span and foam glass shear webs. Virtually all blades use 45° glass on the surface to confer splitting resistance. Some manufacturers use epoxy resin with high quality glass (LM-Aeroconstruct). Carbon fibres are sometimes added to enhance the strength of (generally non-carbon) blades in particular areas.

9.5.2 Up-scaling of blade design

Data for the range of blade masses as employed on medium and large wind turbines is presented in Figure 4.5.2.

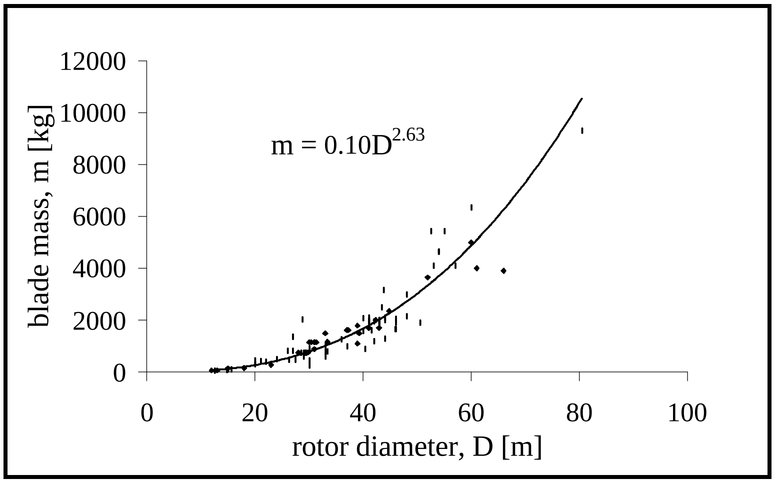

Figure 4.5.2 Scaling of blade mass

It is commonly the case that the largest blades are the most recently manufactured and, being at the top of the manufacturer’s learning curve, take most advantage of latest developments to reduce specific mass and cost. If only blades for rotors greater than 40 m diameter are considered, thereby excluding older smaller blades, the trendline exponent of Figure 4.5.2 rises from 2.6 to 2.8. Blades manufactured in a very consistent way (e.g. ATV blades) have mass and cost that scale approximately cubically.

9.6 Evaluation of scaling trends in present technology

As may be expected, small machines have relatively high tower heights in order to escape the worst effects of the earth’s boundary layer. For wind turbines above about 30 m diameter (Figure 4.6.1), it is evident that, on average, the tower height is proportional and approximately equal to rotor diameter. This choice is a result of both technical and visual considerations.

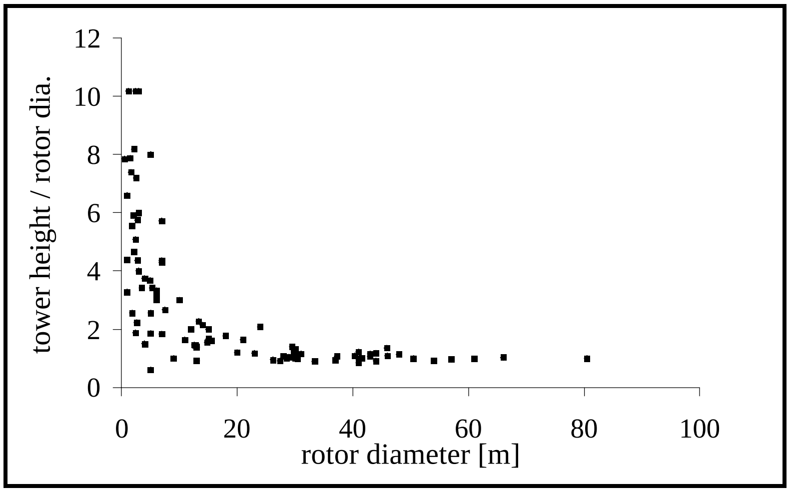

Figure 4.6.1   Scaling of tower height

This fairly consistent picture is obtained by selecting the middle value of tower height in many instances where manufacturers offer a range of tower heights.

The variation of wind speed with height above ground is often represented by a power law with exponent α, and it is readily deduced that the power output of geometrically similar wind turbines will then scale with diameter, D as $D^{(2+3\alpha)}$. The exponent, α, is most typically taken as 1/7 implying a dependence as $D^{2.43}$. It is quite apparent (Figure 4.6.2) the extent to which design practice conforms to this with the data trendline giving an exponent of 2.42.

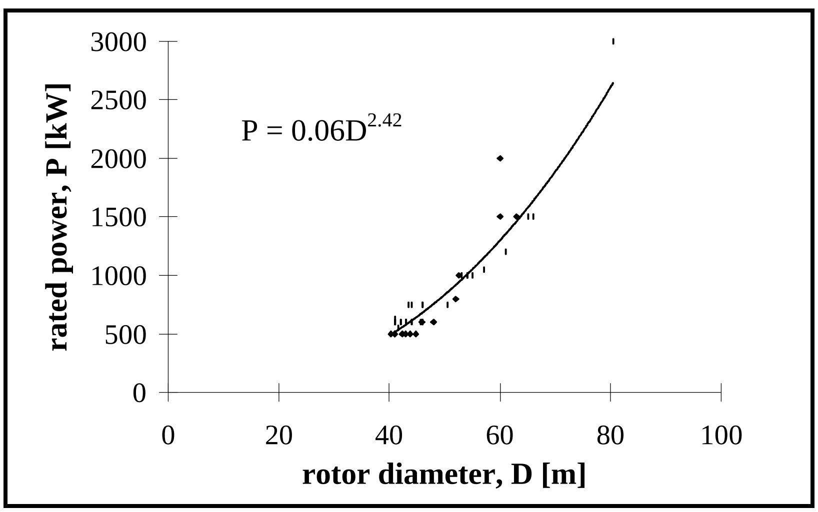

Figure 4.6.2   Power rating of large wind turbines

It would appear (Figure 4.6.3) that nacelle mass scales less than cubically with increasing rotor diameter. However if the smaller (generally older) designs are excluded, the exponent (2.4 in Figure 4.6.3) rises to 2.7.

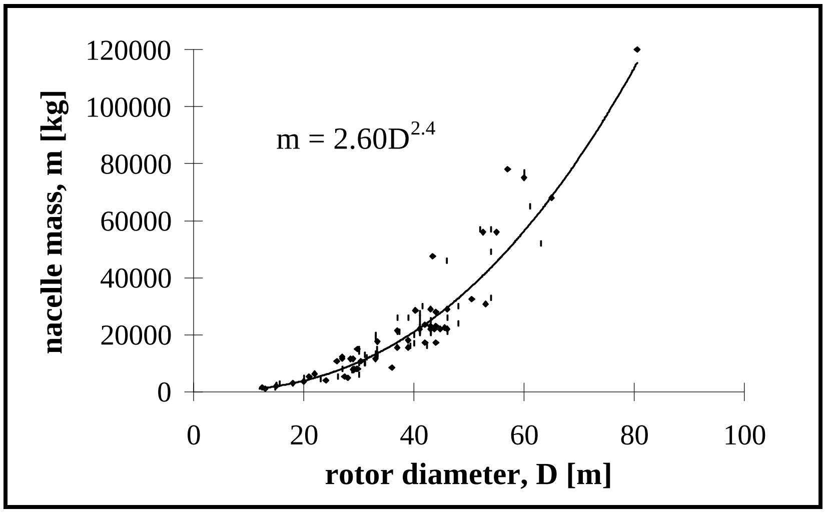

Figure 4.6.3 Scaling of nacelle mass

The mass of a nacelle depends primarily on drive train torque which in turn depends on choice of generator rating and choice of design tip speed. It also depends on applicable design standards and the manufacturer's approach e.g. a preference for simplicity in the use of cheap thick steel plate or more optimum weight reduced fabrications. In Figure 4.6.4 a normalisation is effected that takes account of tip speed and power rating. The data still exhibits much scatter with the most extreme variations being indeed attributable to manufacturer's attitude to weight saving. It is notable, however, than the trendline exponent is now almost exactly cubic.

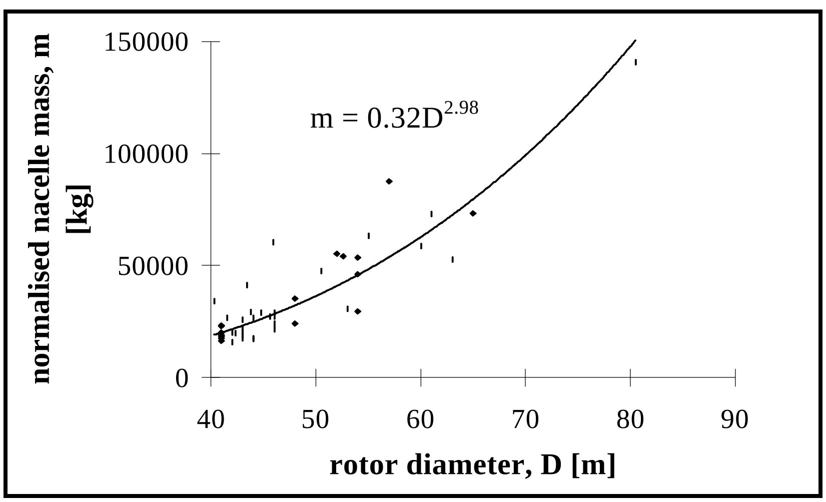

Figure 4.6.4 Scaling of normalised nacelle mass

In a simplistic view of wind turbine scaling, there is often reference to a "square-cube" law. The up-scaling of wind turbines is more favourable than this suggests with the "square" part being more like 2.4 on account of the benefit of increased mean wind speed at increased height above ground. However, there is little basis for mass and costs scaling less than cubically when all variables (especially age of design) are fully taken into account.

Factors beyond direct machine costs such as land utilisation, electrical interconnection etc. contribute to the economic benefit of very large machines. The price/kW of medium and large wind turbines (Figure 4.6.5) is presently rather insensitive to scale and at a low level which reflects market development and technical progress.

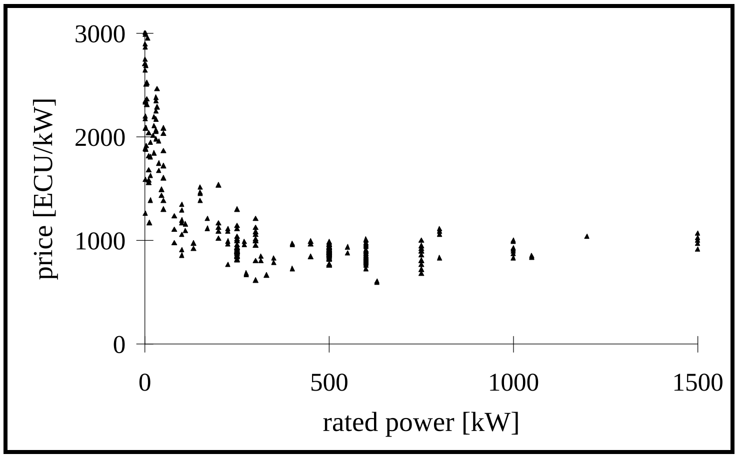

Figure 4.6.5 Price per kW of wind turbines

The price per m^2 of swept area of wind turbines appears disadvantageous for the largest wind turbines (Figure 4.6.6).

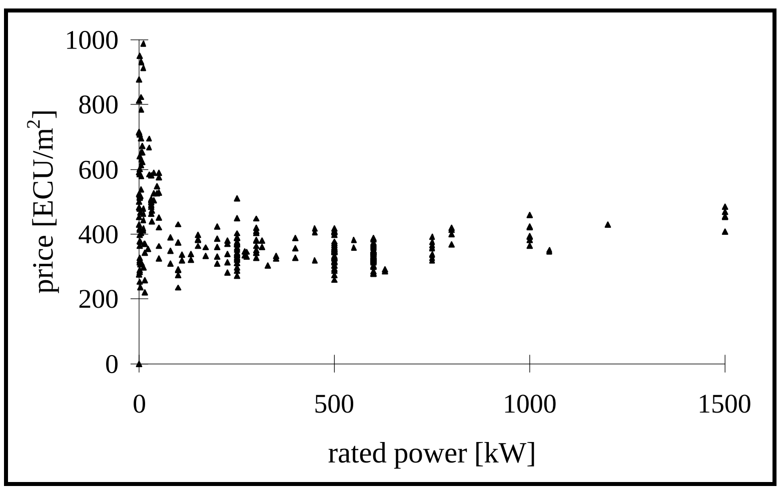

Figure 4.6.6 Price/(swept area) of wind turbines

When this price is better related to relative productivity, however, using $D^{2.4}$ rather than D^2 as was discussed (Figure 4.6.2), there is confirmation that the latest megawatt machines are very similar in specific price to the established medium size designs.

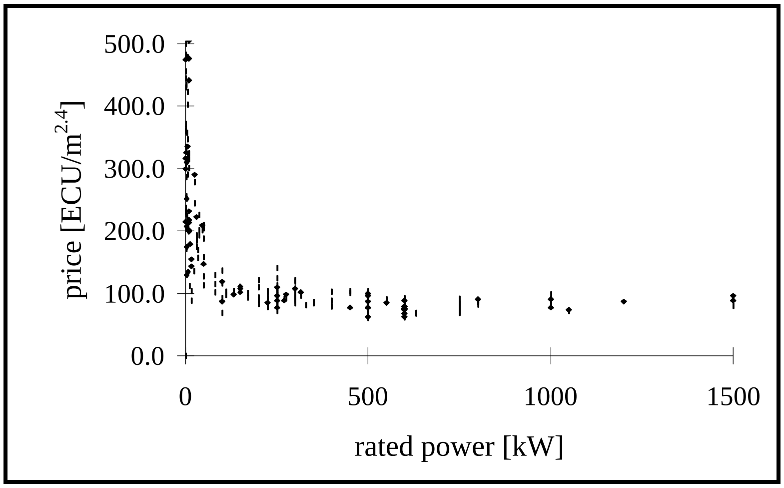

Figure 4.6.7 Price/(normalised area) of wind turbines

Although the largest machines are apparently competitive in specific machine price with medium size, the MW machines are generally the latest and most advanced and the design of medium size machines may be re-visited and further improved. The attraction of larger generating units to utilities and advantages for the exploitation of particular sites are clear, as is also the economic benefit of larger generating units per foundation block in offshore applications.

It is now a critical technological challenge to the industry to assess the limits of up-scaling of present concepts and the cross-over point to new concepts for multi-megawatt generating units.

10 WIND FARM TECHNOLOGY ISSUES

10.1 Wind exploitation in wind farms

The majority of this volume is rightly devoted to the development of the technology which underlies the turbines. Exploitation of wind energy potential does, however, require other skills and engineering disciplines. Large scale exploitation takes place in wind farms - a loose term given to a collection of machines - from a handful to several hundreds. The cost of energy must be minimised to make wind energy competitive with the so called “conventional” alternatives and hence it is not sufficient to consider only the turbines when determining the total cost of wind produced electricity. The balance of plant: civil and electrical engineering accounts for between 15% and 40% of a land based wind farm and may be as much as 50% for an offshore development.

10.2 Balance of plant

The balance of plant consists of the civil aspects: roads, foundations and ancillary buildings, and of the electrical system linking the individual machines to one another and then to the grid. There is usually a transformer at the base of each machine and another at the grid connection; there will also be associated switchgear and metering.

For most wind farms there is a sophisticated monitoring system which allows a remote operator to log and control the wind farm with great precision. This system is known as a SCADA (Supervisory, Control and Data Acquisition) system. The electrical and civil elements of the work are relatively standard but it is clear that, as wind farming has developed into a discipline of its own, the cost effectiveness of the construction and erection process has been greatly reduced. Foundations are now seen to be much more modest than five years ago, partly as the understanding of the loading has improved and partly as the system aspect of a wind farm has been appreciated. Typical erection and commissioning times are now down to one day per machine for a 600 kW turbine. The SCADA systems have developed considerably in both reliability and sophistication and can now add considerably to the effectiveness of the farm. It is now expected as a matter of routine that half hourly records of each machine in a wind farm will be available giving not only the energy yield but also faults, important component temperatures and other health monitoring signals as well as wind speeds and directions and a detailed log of all maintenance tasks and spare parts used.

10.3 Energy predictions and optimisation

The energy yield from a wind farm depends on three ingredients: the machines, the wind and the site. The machines have been considered in detail elsewhere in this volume. The wind and the site are as important in the development of a wind farm and deserve at least a passing reference under this heading of “technology”.

A wind farm must have a lifetime of between 20 and 30 years. In that time it must produce energy sufficient to repay the money borrowed to build it with adequate coverage and returns. The understanding of the long term wind behaviour is thus a vital consideration. In the early days of wind farming the attitude to the proper assessment of the wind was somewhat cavalier and that attitude resulted in some considerable difficulties for the industry. However, there are now sophisticated and reliable methods either through direct measurement or through comparison with nearby meteorological stations which allow considerable confidence to be placed in the wind resource estimates. Its matter is of vital importance for the banks involved in the wind energy industry and hence its future.

The topography of the site can greatly affect the wind at a specific location. The wind speed will tend to accelerate up hill and decelerate down hill. If the slopes are too steep, however, the wind may “separate” from the terrain and produce some damaging excess turbulence and lower mean wind speed. Careful siting is therefore essential. Some major progress has been made in the computation of the local topographical effects by the Danish National Laboratory, RISO, who have published a very “user-friendly” topographical wind flow model “WASP” [10] which allows relatively inexpert users access to a very powerful tool of computational fluid dynamics. Used under the correct conditions this tool can produce reliable results for local flows and has been used extensively by the wind energy community.

The machines within a wind farm interact on with another. This interaction occurs through the wakes produced by the machines. When a machine operates in the wake of another it sees not only a reduced mean wind speed but also a much more turbulent and therefore damaging flow. It is important to keep the machines a safe distance apart but also to keep them close enough to be cost effective. A great deal of effort has been devoted to understanding the behaviour of both individual wakes and whole wind farms. The technology is now relatively mature and, provided flow separation does not occur, there are reliable models for predicting both the energy output and the loads encountered inside a wind farm. New tools are now appearing which allow the topographical and wake models to work together to optimise the layout of wind farms. Sometimes these models can increase the production of a wind farm by as much as 10% compared with designs undertaken “by eye”.

Some new areas of technology have been developed as a result of the permitting issues related to wind farms: wind turbine sound propagation and nuisance, interference with electromagnetic communications, establishment of the visual envelope of a wind farm and realistic photomontages. None of these matters are required exclusively for wind energy but each has needed some special improvements to allow proper consideration of this new type of development. The wind energy industry has risen to this challenge and on each of these subjects new physical and computational tools have been developed, validated and adopted. Accurate information at the planning stage of a wind farm is essential in the preparation of environmental statements to give the local public an accurate and informative idea of the appearance of a wind farm. These new tools have helped to fulfil that requirement.

11 ELECTRICAL INTEGRATION

11.1 Weak Grids

It is by now well appreciated that one of the economic factors limiting the exploitation of Europe’s wind resource is the predominantly weak existing public electricity network in those areas most attractive for installation of wind turbines. The basic problem is that the distribution systems were designed to distribute power to consumers and not to collect it. The problem is therefore an economic one. A large development on a good site may be able to justify building a long feeder to a relatively strong point on the existing network. Some of the main issues are;

11.1.1 Steady-state voltage

The real and reactive power due to the wind turbine or wind farm will affect voltages on the network as it flows through the network impedances. For weaker networks, the effects are greater.

11.1.2 Voltage step changes

Utilities specify limits on the maximum instantaneous step change in voltage that a customer can cause. Wind turbines can cause voltage step changes when starting, or when changing between generators. For very weak points on a network, this issue may be the limiting factor on the number and size of wind turbines that may be connected.

11.1.3 Flicker

Wind turbines result in fluctuations in real and reactive power, and hence voltage, in the utility network. Voltage fluctuations can cause customer annoyance through the phenomenon of 'flicker' where the light intensity from incandescent lighting fluctuates perceptibly. Variable-speed wind turbines generally produce significantly lower flicker than fixed-speed machines. Flicker can be an important issue for weak networks. The limits on the flicker produced by an installation vary between utilities. Some have a fairly simple process, whereas the international standards [11] describes a complex methodology designed to share out equitably the flicker capacity of the network amongst all network users.

11.1.4 Harmonics

On weak rural networks, there can be significant existing levels of harmonics from domestic consumers, which may already exceed the stated limits. These are principally the 5th and 7th orders, peaking in the evenings as televisions are switched on.

11.1.5 Voltage unbalance

On weak networks in rural areas, the majority of customer loads are single-phase. If these are not correctly shared out between the phases, voltage unbalance will result. Induction machines connected to such networks will act to reduce the unbalance, but in the process will be subject to overheating. It is known that in some cases voltage unbalance has been above the specified levels, and significant wind turbine downtime has occurred.

11.2 Power Quality

The issues of flicker and harmonics, and other related issues, come under the heading of “power quality”. A standard for power quality of wind turbines is currently being drafted by a Working Group of the IEC, with members drawn from the international wind industry. The full exploitation of Europe's wind energy potential requires sensible and well considered regulations which govern connection to the grid. There is a need for the wind industry to question the rigid utility criteria based on the ratio of wind turbine capacity to short circuit power, which are resulting in unnecessarily expensive network connections.

The "minimum acceptable network strength" is the minimum short-circuit level of the connection point to which a single wind turbine can be connected without producing unsatisfactory effects (poor power quality) for other consumers. Clearly the smaller this value, the greater the turbine capacity which can be connected to any given point without producing unacceptable effects. Interest in this parameter has been brought about by the reaction of the German utilities to the connection of large numbers of wind turbines to the grid. This points to both an important area of technology development for the industry and an area of techno-political concern.

11.3 Network costs and benefits

The possible costs and benefits to an electricity system due to "embedded" generation (generators connected within the distribution system, close to customers) has been subject of much recent discussion in the industry.

11.3.1 Losses

Energy is lost as electricity is transported from large centralised power stations to the consumers. In some cases, embedded generators are credited with an estimate of the value of this benefit to the network.

11.3.2 Transmission system benefits

Apart from losses, the major part of the costs of running a transmission system is related to the capital cost of providing transmission system capacity, in particular the peak capacity required for only a short period each year. Clearly, embedded generation is situated close to consumer loads, and therefore reduces the demands on the transmission system.

11.3.3 Distribution system reinforcement

The existence of embedded generation can release capacity in a distribution system. This can allow system reinforcement to be deferred and/or allow new customer load to be connected. This provides savings for the utility and, consequently, for its customers. As wind is a highly intermittent generation source, usually without control of power factor, any such benefit is likely to be small, and will be site-specific.

11.3.4 Improved reliability of supply

This benefit arises from embedded generation being essentially dispersed generation on the distribution network. On a meshed distribution network, a fault on one component of the network may lead to overloading of other plant items, and further failures resulting in loss of supply to consumers. Any generation embedded on that network reduces the likelihood of overloading and loss of supply.

11.3.5 Environmental costs and benefit

Environmental costs/benefits of any type of generation are, on the whole, widely acknowledged yet any attempts to put a monetary value on them are usually hotly disputed and rarely accepted. The burning of fossil fuels such as oil, gas and coal produces emissions which, to various extents, cause social and environmental damage which has to be paid for. The full cost of climate change is by no means fully appreciated yet. Increasingly unsettled weather patterns, rising sea levels and increasing incidence of disease all have huge potential social and economic costs associated with them. Possible values for the benefits of renewable generation are discussed in [12,13].

12 STANDARDS AND CERTIFICATION

12.1 Wind turbine certification

The certification of wind turbines has become an increasingly important requirement for the industry, not only in Europe but now further afield in the previously unregulated market of the US and the emerging markets in South America, Asia and Australasia. In markets where there may be no legal requirement, certification is often a commercial necessity in order for a wind project to attract investment and insurance cover.

In northern Europe, particularly in Denmark, Germany and the Netherlands, certification of wind turbines has long been required in order for wind projects to obtain building permits and/or to become eligible for subsidies. In these three countries rules and standards have been developed as the basis of certification and these have had a direct influence on the design procedures adopted by manufacturers. The relevant national standards and certification rules are:

- (in Denmark) The Danish standard DS 472 [14] and the “Technical Basis for Approval and Certification” [15],
- (in Germany) Deutsches Institut für Bautechnik (DIBt) Regulation for Wind Turbines” [16] and the Germanischer Lloyd (GL) “Regulation for the Certification of Wind Energy Conversion Systems” [17],
- (in the Netherlands) The “Technical Criteria for the Type Certification of Wind Turbines”, NEN 6096/2 [18].

There are significant differences between these various national standards and certification rules. These differences range from different design load cases and safety factors through to different requirements for the wind turbine safety system. Harmonisation of standards and certification rules has been a major driver behind the international initiatives described below.

In addition to the standards and certification rules listed above, there is a further set of regulations which has been published by Germanischer Lloyd specifically for the certification of offshore wind turbines [19]. These regulations provide at present the only available guidelines for the design of offshore wind plant.

12.2 International standards

In 1987 the "Committee of Action" of the International Electrotechnical Committee (IEC) decided that there was a need to begin the development of international standards in the field of wind energy. A technical committee IEC/TC88 was initiated and Working Groups set up to focus on a range of technical areas. Since 1987 international standards have been developed and approved as follows:

- IEC 1400-1: "Safety of Wind Turbine Generator Systems"
- IEC 1400-2: "Safety of Small Wind Turbines"

These two standards are now assuming considerable importance in the world wide wind industry.

Two further IEC standards are presently in the final stages of approval. These standards cover the areas of acoustic measurement techniques and power performance measurement techniques for wind turbines. In addition IEC/TC88 Working Groups have been set up to prepare standards and guidelines in the following areas:

- Revision of IEC 1400-1
- Blade testing methods
- Standardisation of certification methods
- Power quality
- Mechanical load measurements

As a separate initiative and in order to promote harmonisation throughout the European "internal market", the EU Commission has issued a mandate to the European standards organisation responsible for electrical matters, CENELEC. This mandate requires CENELEC to develop standards for wind turbines within the European market. The CENELEC activities are well advanced and it is clear that wherever possible the emerging standards will be based on the equivalent IEC documents.

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European Commission
Directorate-General for Energy

WIND ENERGY - THE FACTS

Volume 2

COSTS, PRICES AND VALUES

EXECUTIVE SUMMARY

1 INTRODUCTION

No single value can be assigned to the price of wind energy. The same is true of energy prices for thermal plant. It is important to distinguish between the cost of plant (such as wind turbines and wind farms) and the price of the electrical energy they produce. Capital costs are primarily a function of the size of the installation (due to economies of scale). Energy prices depend on wind speeds and institutional factors, and have two components:-

- Capital charges, including depreciation and interest charges
- Operating costs

The calculation of wind energy generation prices follows procedures which are reasonably standardised across the power industry. "Real", i.e. net of inflation, interest rates (test discount rates) - are used. National interest rates and repayment periods vary widely across the EU, but reference energy prices may be derived provided the levels are quoted.

Institutional factors account for most of the apparent variations in quoted wind energy prices. In Denmark, for example, the costs of grid reinforcement for wind installations are not always charged to the developer.

2 WIND ENERGY PRICES

Price trends: The cost of wind energy wind plant has fallen substantially during the last fifteen years, and this trend is continuing. Energy prices have fallen even faster, due to lower wind turbine costs, higher efficiency and availability, and lower operation and maintenance costs. Wind turbine prices fell by a factor of at least three from 1981 to 1991, and energy prices have halved in the last 9-10 years.

Current energy prices: The price of modern turbines around the 45 m diameter mark is around 700 ECU/kW. It may be noted that the "most economic size" has changed over the years and is still moving upwards. The larger the machines the fewer are required for a given capacity. This brings savings in site costs and in operation and maintenance costs. Overall, balance of plant costs add between 15 and 40% to wind turbine costs, depending on the number and size of machines in the wind farm, and the location. The windiest sites - on hilltop sites, often remote from a grid connection, or coastal locations where deep piling into silt is needed, tend to incur costs above average. Operational costs vary between countries and between wind farm sites; they range from around 25 ECU/kW/yr for 200 kW machines, falling to around 15 ECU/kW year for 500 kW machines.

Current energy prices corresponding to a mid-range wind farm cost of 850 ECU/kW are 9.6 cECU/kWh at 5 m/s, declining to 3.4 cECU/kWh at 10 m/s. (All wind speeds refer to hub height). These assume a 7.5% test discount rate and depreciation over 20 years.

National institutional frameworks influence discount rates and depreciation periods, and vary across the EU. Local wind speeds also vary widely across the European Union.

The best resources are in the upland regions of Ireland, Britain and Greece, parts of southern France, Spain and the Canary Islands, where average wind speeds (at hub height) may be around 8-10 m/s. In Western Denmark, speeds range up to about 8 m/s, while the coastal regions of north Germany range up to about 7.5 m/s. Elsewhere winds are lower, with speeds decreasing further inland.

Offshore wind has the potential to deliver substantial quantities of energy - at a price which is cheaper than most of the other renewable energies. Wind speeds are generally higher offshore than on land, although the upland regions of the British Isles, Italy and Greece, do yield higher speeds.

3 ENERGY PRICES FROM COMPETING FUELS

The electricity generation prices from thermal plant in the EU vary widely. Government support for the nuclear and coal industries may mean that the real generation prices are higher than is apparent. Comparisons between the price of wind energy and of electricity from the thermal sources ignore the fact that, in many instances, renewable technologies deliver energy closer to consumer demand than centralised generation.

Electricity prices for thermal plant, moreover do not include the so-called "external costs" of electricity generation - those associated with damage to health and the environment.

4 FUTURE PRICE TRENDS

There are a number of factors which are causing a steady fall in the cost of wind energy systems:-

- The trend towards larger wind turbines
- Falling infrastructure costs
- Possible reductions in the cost of raw materials

Data from the European Renewable Energy Study (TERES II)(DG XVII), indicate that wind may become one of the cheapest renewable energy sources, with prices within the range of those of the thermal sources. Energy prices from the thermal sources are, however, subject to uncertainty.

5 CONCLUSIONS

Wind plant costs and wind energy prices have been falling steadily and there are strong indications that this trend is continuing. No single figure can be assigned to price of wind energy, as wind speeds, interest rates, amortisation periods and plant costs vary across the EU, but on best sites, current wind prices are within ranges quoted for thermal plant.

- External costs of thermal plant need to be taken into account when making comparisons with wind energy prices. Some external costs, like the cost of coal support in Germany, are irrefutable. Others more difficult to quantify, but nonetheless real.
- Wind energy must also be credited with additional value, as it is usually injected into low voltage distribution networks, enabling utilities to save on transmission and other costs.
- Offshore wind energy prices are now moving down rapidly and will probably continue to do so, as new installations are commissioned.
- There is considerable scope for future price reductions.

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1 INTRODUCTION

There are no absolutes in energy prices. No single number can be assigned to the price of wind energy. The same is true of energy prices for thermal plant. Unless all the relevant assumptions are clearly set out, single numbers are virtually meaningless.

This paper includes a brief summary of past trends in wind plant costs and energy prices. It then examines current price levels, and the influence of capital costs, wind speeds, operation and maintenance costs, interest rates and other institutional factors such as capital depreciation periods.

Price comparisons with coal, gas, nuclear and other renewable energies are also included, and "system integration" issues are examined, including energy and capacity credits, how the value of wind energy in utility networks is affected by its variability, and the value of distributed generation.

The paper concludes with a review of published forecasts of future price trends.

2 DEFINITIONS AND CALCULATION METHODS

2.1 Definitions

To the layman, costs are what must be paid to acquire items and prices are the amount for which items are sold or offered. Value is the worth of an item to the recipient. The context must therefore be clear. Manufacturers incur costs when building wind turbines, and sell them at a price which includes their profit. From the perspective of a wind energy developer, however, he will incur costs throughout the lifetime of the project, which include the turbines, and sell the energy at a price which includes his profit. Inputs are therefore costs, and the output is a price. This is the perspective used in this paper.

Economic theory yields different definitions, and the economist's perspective includes wider and more complex issues, not relevant to this paper. The focus is more on the role of costs and profits as determinants of decision-making in organisations concerned with allocating resources to particular activities. "Economic opportunity cost" considers the value of the next best thing which could have been produced with the same resources, and takes into account the opportunity cost of capital, land and time (**1**). The relevant interest rates, however, vary with time, place and activity, and tend to be lower than the reference levels used in many energy price calculations. The use of reference levels, however, (typically 5 or 10%), makes no assumption about profit levels, which may be positive or negative, but the price levels clearly do not necessarily equate to the economic costs. Procedures for calculating economic costs may be found in standard texts on energy policy, and a detailed review may be found in reference (**2**).

Cost inputs: There are two cost inputs to a wind developer or owner. The capital, or installed, costs of the plant are most frequently quoted in terms of investment cost per installed kilowatt, or ECU/kW, and, broadly speaking, are primarily a function of the size of the installation (due to economies of scale). Operating costs are the second input, and, similarly, depend on size, and may be dependent also on capacity or energy yield.

Energy prices: These depend on installed costs, wind speeds, test discount rates and capital repayment periods, and are simply the sum of the capital cost element and the operating costs, and are usually expressed in cECU/kWh, although ECU/MWh is also used.
The term "reference price" is used in this paper to denote energy prices calculated using standard procedures, with fixed interest rates. These must be distinguished from prices relevant to particular EU states, which use appropriate levels of interest rate and repayment period; these are given the generic name "national prices".

2.2 Price calculation methods

The basic procedures for setting selling prices for electricity are set out in standard textbooks, e.g. (2). The first step is to calculate the annual capital charge, which depends on the project interest rate, or "test discount rate" and repayment period. An "annual charge rate" is used, which expresses the fraction of capital cost which needs to be charged each year in order to yield the required rate of return over the specified period.

The annual capital charge includes capital depreciation and interest charges, and is divided by the annual energy output to yield the capital element of energy price. The energy output of wind plant is primarily dependent on the wind regime, i.e. on its geographical location, and on the performance of the wind turbines.

Institutional factors arguably account for most of the apparent variations in quoted wind energy prices. These factors may also influence the exact make-up of capital and operating costs. In Denmark, for example, the costs of grid reinforcement for wind installations are not always charged to the developer. Similarly, utilities in Denmark and elsewhere may not always charge their overheads to "operating costs", whereas in Britain, by contrast - where wind developments are undertaken by private developers - all costs are included.

2.3 Recommended Practices

The calculation of wind energy generation costs follows procedures which are reasonably standardised across the power industry. The International Energy Agency has published guidelines in the form of a "Recommend Practice" (**3**) for wind energy, and these are similar to those used for other renewables and for thermal plant. The IEA document advocates the use of "real", i.e. net of inflation, interest rates - more accurately, test discount rates - for the calculations, which is also common practice.

The following items are included in energy price calculations:-

- planning costs)
- capital cost of plant) Capital
- construction costs)
- interest during construction)
- land costs (either as part of the capital or as annual leasing payments)
- fuel costs - zero for renewable energy plant
- operating costs (O & M), including labour, materials, rents, taxes and insurance
- decommissioning

The IEA document recommends that capital costs are amortised over the technical life of the plant and that standard test discount rates are used. While this may produce useful data for comparative purposes, actual interest rates and amortisation periods are controlled by regulatory or institutional frameworks, as noted above. Each of these parameters needs, therefore, to be considered in more detail.

A useful parameter which reflects the dependence of energy cost on wind speed is the "cost per annual unit of output", simply obtained by dividing installed cost by annual output, and expressed in ECU/Annual MWh. This is useful for comparative purposes, as it does not depend on interest rates or depreciation periods.

2.4 Interest rates

Public sector companies use test discount rates set by Government. These vary in the EU, generally between 5% and 8%. Private companies set their own rates. In practice, many projects are financed using a mixture of loan and equity funding. A typical ratio is 80/20. If the loan interest rate is, say 6%, and the equity return is 25%, the equivalent test discount rate is 10%. The reference energy prices in this paper, which are not specific to particular states, use sample discount rates of 5 and 10% - in line with conventions for thermal plant, **(3,4)**.

2.5 Amortisation periods

Amortisation and depreciation periods also vary, and are not necessarily as long as the life of the plant. This is rarely used outside the public sector. The IEA Recommended Practice notes that “20 years is commonly used for proven grid connected wind turbines” and is used in this paper as a default value.

2.6 Typical interest rates and repayment periods

Table 1 shows sample European data and Figure 1 illustrates how repayment periods and interest rates influence energy prices, for wind and combined cycle gas turbine plant (CCGT). Energy prices for CCGT plant are less sensitive to these factors, as the capital element of the energy price is lower. The data used in Figure 1 are set out in Table 2.

It should be noted that the data in Table 1 can alter. To quote an example - before privatisation, in the UK it was assumed that capital was repaid over the life of the plant. Later, capital had to be repaid within about six years for most projects in the second round of the Non Fossil Fuel Obligation (NFFO), since premium prices ran out at the end of 1998. Later rounds of the NFFO offered contracts for 15 years, but this did not necessarily define the amortisation period. The technology at that time was seen as fairly new, so bank loans were limited to around 10/12 years (**5**). More recently this period has been extended.

Location	Interest rate, % real	Repayment period	Reference
Denmark	7	20	4
Germany	Varies, 5 upwards	10	4
The Netherlands	5		4
Portugal	10		4
United Kingdom	Developer's choice	15	

Table 1 Interest rates and repayment periods used for wind plant

Technology	Wind	Gas
Capital cost, ECU/kW	1000	724
Build time, year	0.5	1
Load factor, %	0.26	0.8
Fuel cost, cECU/kWh	0	3.3
O & M cost. cECU/kWh	1	0.6

Table 2 Plant data used to illustrate effects of interest rates and repayment periods

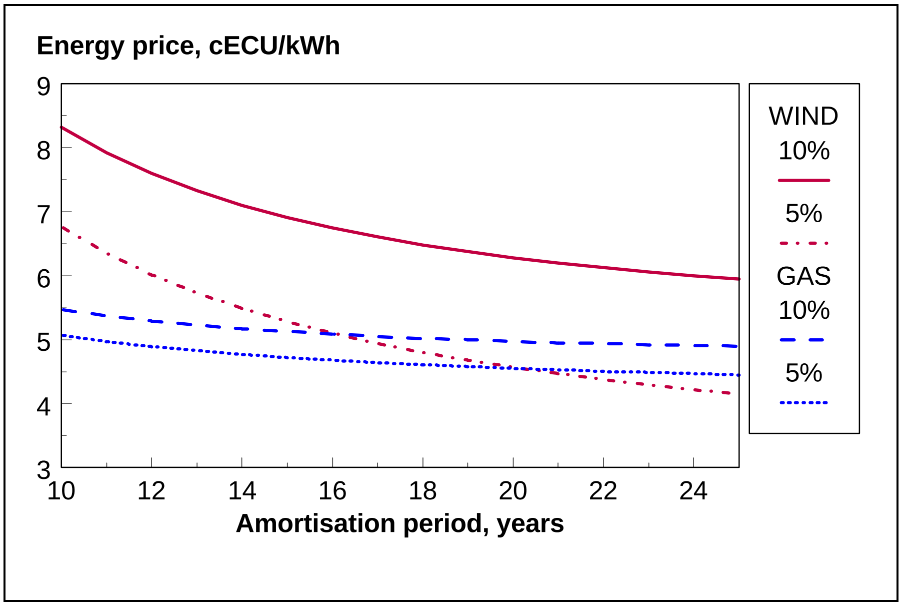


Figure 1 Energy prices - influence of interest rates and repayment periods

3 HISTORICAL SUMMARY

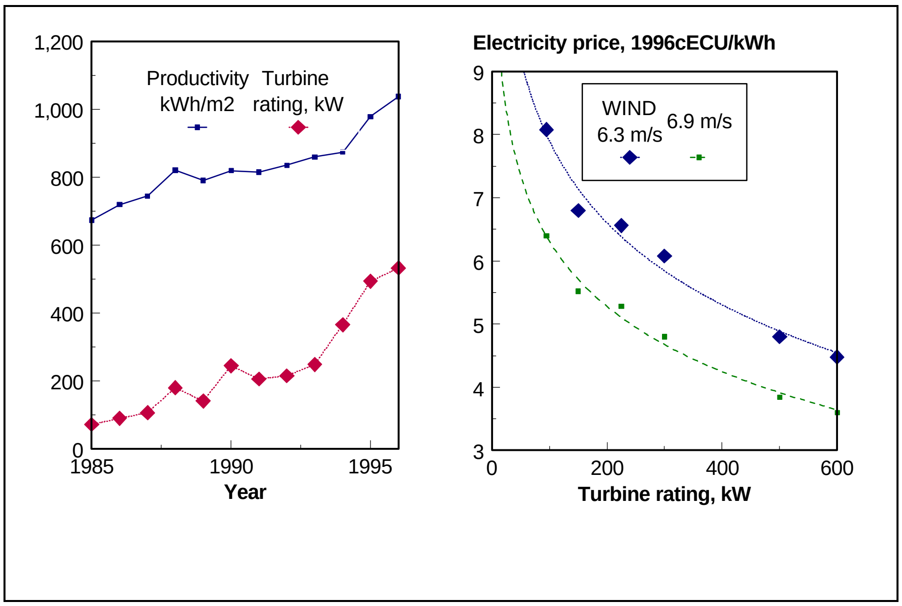
The cost of wind plant has fallen substantially during the last fifteen years, and this trend is continuing. The reduction in energy prices has been greater and is due to:-

- Lower wind turbine prices
- The turbines are larger, with taller towers (so the wind speeds intercepted by the rotors have increased). Most machines installed in the 1980s were around 50 kW in size whereas modern wind farms use 600 to 750 kW machines.
- Better understanding of the technology and improved production methods

- Efficiency and availability have improved.
- Operation and maintenance costs have fallen.

Several studies have reported these movements in prices. The results differ, since they depend on the precise way the data were collated, but there is broad agreement that wind turbines prices fell by a factor of at least three from 1981 to 1991, and energy prices by a factor of about 4. Prices have halved in the last 9-10 years **(6).**

The way in which machine sizes and productivity have increased in shown in Figure 2. The average size of wind turbines installed in Denmark increased from 71 kW in 1985 to 523 kW in 1996. The productivity of new machines increased from 673 kWh/sq m in 1985 to 1037 kWh/sq m in 1996. (7). The link between turbine sizes and energy prices has also been analysed (6), indicating a 44% reduction from the early 95 kW machines to the 600 kW size. This is shown in Figure 3. The overall trend in Danish wind energy costs over the last 10 years, assuming a 6.3 m/s site, 5% interest rate and 20 year life, is illustrated in Figure 4, which shows an 8% per annum fall in prices.



Figures 2 and 3 Danish wind turbine sizes, productivity and energy prices

The minimum bid prices for wind energy in the UK NFFO are also shown in Figure 4, and show a similar rate of fall. The appropriate wind speeds and interest rates are not known; minimum bid prices are shown as these are not influenced by the size of the NFFO orders.

This summary of historical trends is intended to give a broad picture of price movements; the energy prices quoted are comparable as far as possible but the all-important question of wind speeds, test discount rates and depreciation periods need to be taken into account when making more detailed comparisons between costs, particularly across national boundaries.

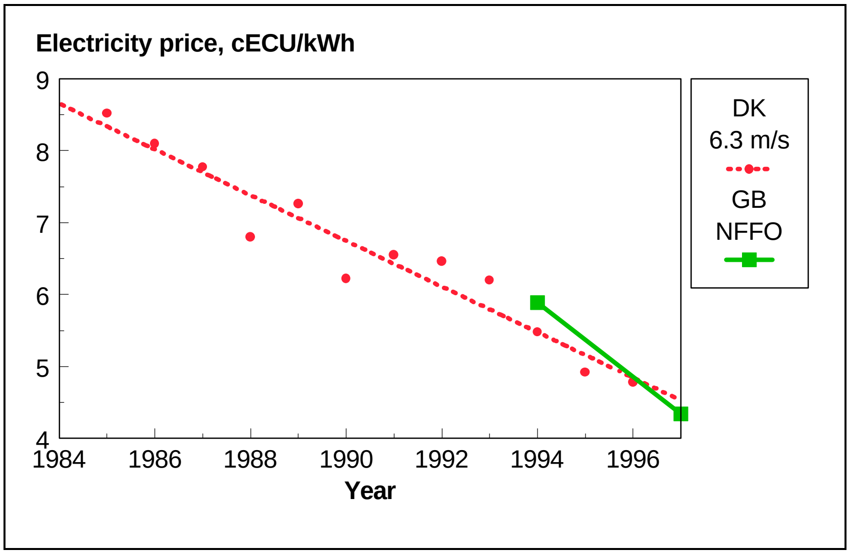


Figure 4 Energy price trends

4 CURRENT PLANT COSTS

4.1 Methods of presentation

Wind turbine and wind farm costs are often quoted on the basis of a price per unit of installed capacity (ECU/kW), but such data can be misleading as manufacturers have differing design philosophies - there is no fixed relationship between rotor size and rating. A 40m machine, for example, may have a rating anywhere between 350 kW and 500 kW. The price of a machine with a high rating, relative to its size, will therefore tend to appear low when compared with one which has a low rating for its size. More reliable comparisons may be made by comparing prices on the basis of price per unit swept area (ECU/sq m). However, although this may be more rigorous it is probably less readily understood. Both methods of presentation are used in this paper, with comparisons on the basis of the rated output being preferred, provided it does not lead to ambiguity.

The analysis of current energy prices uses data for machines around 500-600 kW rating, as these are currently being deployed in large numbers around the EU and generally give the lowest energy prices.

4.2 Key factors

4.2.1 Installed costs

Turbine prices: Danish wind turbine prices are representative of EU levels, and published price lists facilitate analysis. Price data are shown in Figure 5. There is no clear link between price per unit swept area and size, and the price of turbines around the 45 m diameter mark is around 300 ECU/sq m. It may be noted that the "most economic size" has changed over the years and the relationship between size and price is discussed in Appendix A.

<u>Balance of plant costs</u>: Wind turbine prices, discussed above, vary little with size, but there are sound reasons for pursuing the development of large machines. The use of large machines means fewer are required for a given capacity, and a number of items in the "balance of plant" cost category decrease with machine size, or machine numbers, especially:-

- Foundation costs
- Electrical interconnection costs
- Access tracks

Analytical studies have shown that the contribution of balance of plant costs to overall energy costs can be reduced by around 25% by moving from machines of the 300 kW size range to 1 MW size machines **(9)**. These trends are explored further in Appendix A

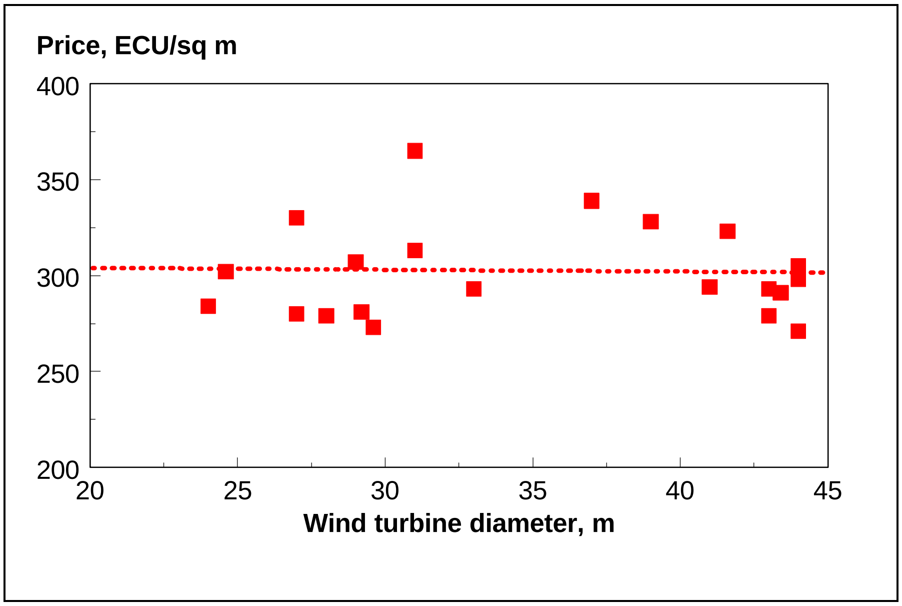


Figure 5 Turbine prices - Denmark

Balance of plant costs add between 15 and 40% to wind turbine costs, depending on the number and size of machines in the wind farm, and the location. The windiest sites - on hilltop sites, often remote from a grid connection, or coastal locations where deep piling into silt is needed, tend to incur costs above average. Table 3 summarises the components of “balance of plant costs”, and shows typical values (**10-12**). National institutional factors affect the precise mix of items; “land purchase”, for example, reflects German practice, whereas landowners tend to be paid a rent in Britain. If the turbine owner also owns the land, however, there is unlikely to be a rental charge.

Item	**Costs, % turbine price**

	Range
Foundations	5-11
Electrical connections	5-11
Land purchase	0-5.7
Planning costs	1.5-3
Approvals	3-8
Infrastructure	2-4
Management	3-6
Miscellaneous	2-4
Grid connection	7.5-15
TOTAL	15-40

Table 3 Wind farm balance of plant costs

4.2.2 Installed costs and wind speeds

Installed costs tend to rise with increasing wind speed, as noted in the previous section. This reflects the fact that developers can afford higher costs, if they get a higher yield. Increasing the wind speed e.g. from 8 to 9 m/s at hub height will typically increase output from a wind turbine by 10 per cent. The link between prices and winds has been examined for Britain **(13, 14)** and Germany, and similar trends found, see Appendix A. A further factor which influences this correlation is that tall towers are often used in Germany to obtain higher wind speeds, but at increased turbine cost. For the purpose of this analysis, it is assumed that costs increase linearly by 8% per m/s increase in wind speed, above 7 m/s at hub height.

4.2.3 Operational Costs

Operational costs vary between countries and wind farms. As some elements are fixed annual sums, wind farms on high wind speed sites may have lower costs. Table 4 shows the main components and the usual basis of charging is underlined. Some costs are size-dependent (see Appendix A), but entries relate to machines in the 500-750 kW range. Total costs are around 25 ECU/kW/yr for 200 kW machines, falling to around 15 ECU/kW year for 500 kW machines.

Item	ECU/kW/year, or other cost basis	cECU/kWh (approx)
Service contract	4-8, or based on output	0.15-0.6
Administration	Cost basis varies	0.1-0.3
Insurance	<u>4-7</u>	0.15-0.5
Land rent	0-4, <u>1-2% of revenue, if charged</u>	0-0.4
Local rates	<u>0-5</u>	0-0.2
Electricity usage	Standard tariffs	0.05-0.2
Reactive power	<u>Up to 0.4 kVArh</u>	0-0.1
TOTAL	Up to 24 ECU/kW/year	0.6-1.5

Table 4 Operational costs - 500 kW turbines

Not all utilities charge for reactive power - and not all machines need it. Land rent may be an explicit cost if a developer builds on land he does not own, but may not appear if the wind farm operator owns the land. In the latter case the cost of the land may be included in the overall capital cost, or the owner may simply receive remuneration from the overall profit.

4.2.4 Size of wind farm

The size of a wind farm influences its cost, as large developments:-

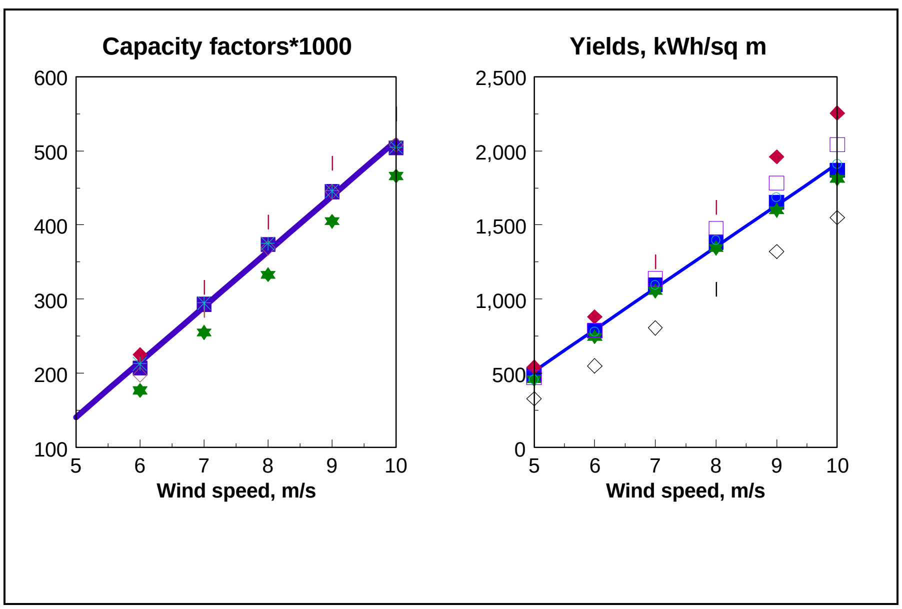
- may attract discounts from wind turbine manufacturers
- enable site infrastructure costs to be spread over a number of machines, reducing the unit cost
- may enable more effective use of maintenance staff

These issues are examined further in Appendix A

5 WIND ENERGY PRICES

5.1 Influence of wind speed

Wind energy prices are critically dependent on site wind speeds, so links between wind speed and machine productivity (in kWh/sq m and kWh/kW) need to be established for the purposes of generalised analyses. Energy yield data for a number of modern machines were collated and these show that capacity factors are typically around 0.2 at 6 m/s, rising to 0.45 at 9 m/s (at hub height). Yields are typically around 750 kWh/sq m at 6 m/s, rising to 1600 kWh/sq m at 9 m/s. These data are shown in Figures 6 and 7.



Figures 6 and 7 Capacity factors and yields for modern machines (500-750 kW)

Wind speeds vary widely across the European Union. The best resources are in the upland regions of Ireland, Britain and Greece, parts of southern France, Spain and the Canary Islands, where average wind speeds (at hub height) may be around 8-10 m/s. In Western Denmark, speeds range up to about 8 m/s, while the coastal regions of north Germany range up to about

7.5 m/s. Elsewhere winds are lower, with speeds decreasing further inland. Information on wind speeds is given in the European Wind Atlas (**8**).

5.2 Reference prices

Although wind energy prices, as noted earlier, depend on national institutional frameworks, reference values may be calculated, using the IEA "Recommended Practice". The wide range of interest rates and other factors must be acknowledged and so indicative low, average and high prices are used. The assumptions are set out in Table 5, and the data apply to machines in the size range 600-750 kW. It is assumed that installed costs increase with wind speed above 7 m/s by 8% per m/s, as noted earlier. Energy production has been derived assuming that array, availability and other losses account for 10% of the gross energy. (Actual losses may be less, as availability levels of 98% and above are achieved by many turbines, but the guaranteed level is usually 95%. This is normally the basis of investment decisions). The energy prices corresponding to the mid-range costs are 9.6 cECU/kWh at 5 m/s, declining to 3.4 cECU/kWh at 10 m/s. The data are shown in Figure 8.

Price parameter	Low	Average	High
Installed cost, ECU/kW, at 7 m/s (hub height)	700	850	1,000
Real interest rate, %	5	7.5	10
Construction period, years	0.5	0.5	0.5
Amortisation, years	20	20	20
Running costs, fixed, ECU/kW/yr	12	18	24
Running costs, variable, cECU/kWh	0.2	0.3	0.4

Table 5 European reference wind energy prices - summary

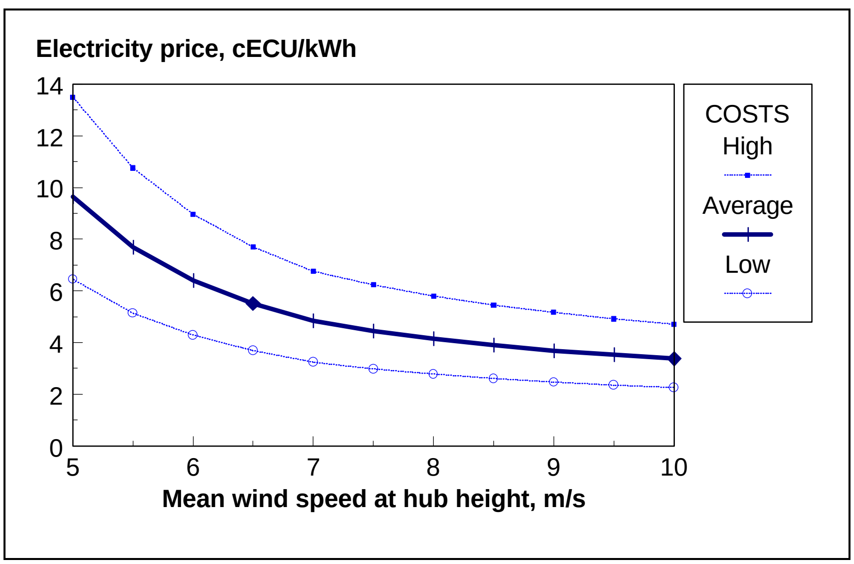


Figure 8 European reference wind energy prices

5.3 National wind energy prices

National institutional frameworks control actual electricity price levels, as noted earlier, and these vary across the EU**(27)**. In practice, also, renewable energy plant are often supported by specific price mechanisms.

The financing of German wind farms, for example, is complex, but a recent appraisal **(15)** suggests that an effective real interest rate of 6.5% and an amortisation period of 10 years is currently used to derive energy prices. The strong dependence of energy price on wind speed has been examined by the German Wind Energy Institute - DEWI **(16)** and recent estimates are shown in Figure 9.

The length of contracts under the British Non-Fossil Fuel Obligation also influences prices. This is set at 15 years, and as all developments are undertaken by private companies, the test discount rate is unlikely to be less than 7.5%. Wind farm prices in the UK are in line with the "Maximum" levels in Table 5. Energy price estimates based on these assumptions are shown in Figure 9, for comparison with the German data. It may be noted that few wind farms in Germany have winds above 7.5 m/s, and few in Britain have winds below 7.5 m/s.

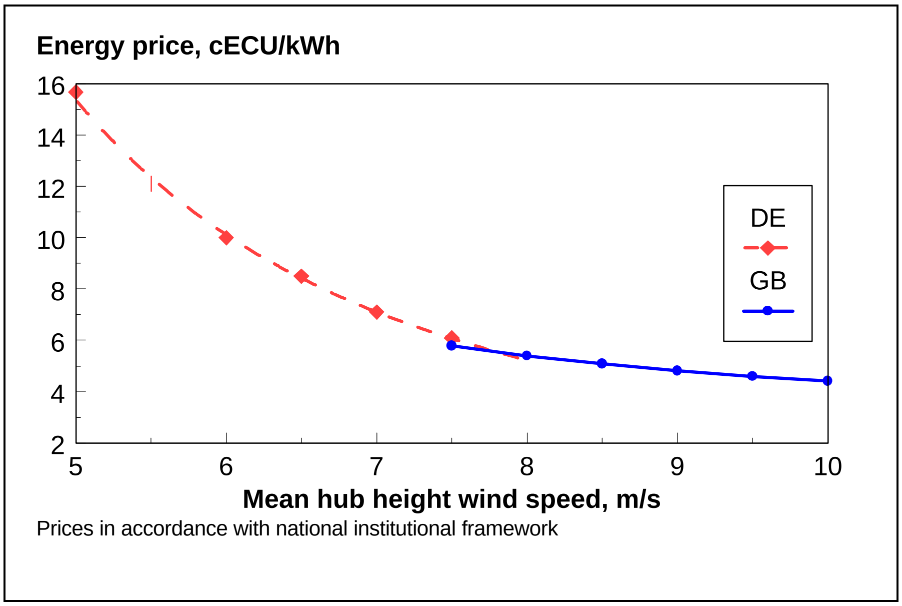


Figure 9 Typical wind energy prices

Table 6 shows wind plant installation costs and other data from across the European Union **(17-21)**, but it should be noted that fewer data are available outside Denmark, Germany and Britain, so the figures in the Table are only samples. Plant costs, wind speeds and energy prices are mostly within the ranges discussed in the analysis of Danish, British and German data, although the important influence of wind speeds and test discount rates in defining energy prices needs, again, to be emphasised. It should also be noted that methods of paying for wind energy vary (**22**), and remuneration may be linked to electricity tariffs rather than the price of wind energy. The Netherlands is a case in point. Similarly, investment subsidies may influence energy prices, and hence the price data in Table 6 may not necessarily derive from rigorous application of the procedures discussed in this paper.

Location (Reference)	**Location**	**Machines (Number/type/kW)**	**Installed Cost**	**Energy price (cECU/kWh)**
France **(17)**	General analysis	Minimum energy price at 800 kW	28% above turbine cost	5 at 7.5 m/s (15 yr life, 8% tdr)

Greece **(18)**	General analysis	Not specified	1000-1330 ECU/kW	2, winds/tdr not quoted
Netherlands **(19)**	Gronigen area	40/Lagerwey/80	4.83 MECU (1510 ECU/kW)	5.8 (paid by utility)
Norway **(20)**	Central Norway, general data	500 kW, effect of machine numbers on cost of wind farms	997 ECU/kW for 1, falling to 990 for 10 machines	4-8, winds 6-7.9 m/s, 7% tdr, 20 yr life
Spain **(20)**		67/Ecotecnia/225	15.9 MECU (1055 ECU/kW)	
Sweden **(18)**	General analysis	400-500 kW	932 ECU/kW	3.6-4.3, with 2200 kWh/kW (5% tdr, 25 yr)

Table 6 European wind farm data

6 OFFSHORE WIND ENERGY

Offshore wind has the potential to deliver substantial quantities of energy - at a price which is cheaper than most of the other renewable energies, but more costly than onshore wind. Offshore wind energy has the added attraction that it has minimal environmental effects and, broadly speaking, the best European resources are reasonably well located relative to the centres of electricity demand.

Wind speeds are generally higher offshore than on land, although the upland regions of the British Isles, Italy and Greece, do yield higher speeds. In the UK, for example, onshore winds at hilltop sites range up to 9 m/s at hub height - higher in some instances - whereas offshore winds at, say, 5 km from the East Coast are around 8 to 8.5 m/s. Offshore wind power is therefore most attractive in locations such as Denmark and the Netherlands where windy hill top sites are simply not available. In these areas offshore winds - which increase with distance from land - may be 0.5 to 1 m/s higher than onshore, depending on the distance offshore.

Several offshore wind farms have now been built, so it is possible to assess the economics in the light of operational experience. This analysis is carried out in Appendix B.

7 ENERGY PRICES FROM COMPETING FUELS

The electricity generation prices from coal, gas, hydro, oil and lignite - the fuels most commonly used across the EU - vary widely. There is no single price that can be assigned to any source of generation, as discussed in section 2. The institutional arrangements which influence discount rates and amortisation periods are, again, frequently the dominant factor in setting energy prices from thermal and hydro plant, but variations in plant and fuel costs also play a part. Government support for the nuclear and coal industries also means that the real generation costs are higher than is apparent.

For example, the pithead price of coal in Germany is more than three times the world market price, so the *true* generation price from coal there is over 9 cECU/kWh (The utilities do not actually pay the higher price, as an annual subsidy of 7400 million DM is paid by the taxpayer to the coal industry. This is a classic example of a "hidden", or "external" cost - a concept discussed in Appendix C).

Capital costs for large combined-cycle gas turbine (CCGT) plant are falling as the "dash for gas", in Britain and elsewhere, leads to intense competition. Gas prices, however are moving upwards. All future coal plant is likely to be fitted with flue gas desulphurisation plant and increasingly stringent controls on emissions may raise plant costs. "Clean coal" technology is being explored, but dramatic changes in generation prices in the short term are unlikely.

The price and costs of nuclear power are the subject of much debate. One key issue is the difference between "mature" plant costs for a series of Pressurised Water Reactors (the most popular option) and "first of a kind" costs, which are inevitably higher. With the exception of France, "production runs" of nuclear plant are rare. Further uncertainty arises from the treatment and precise level of decommissioning costs. Nuclear generation price estimates therefore span a wide range and a UK government review of 1995 quoted 5.2-8.5 1995cECU/kWh (rebasing the prices from the 1990 levels used). Nuclear prices may also exclude hidden external costs: accident risks, for example, are often borne by governments, relieving utilities of the need to pay insurance premiums..

The status and costs of thermal plant are summarised in Table 7. The energy prices have been derived using a 5% discount rate - to correspond with one set of wind price estimates. This yields lower prices for nuclear than those which stem from systems which have been privatised. These prices are compared with wind energy prices in Figure 10.

Plant	Capital cost, ECU/kW	Fuel cost, cECU/kWh	O&M cost, cECU/kWh	Total cost, cECU/kWh
Gas	450-700	1.7-2	0.4-0.6	3.1-4
Coal	1000-1300	1.8-2.3	0.7-1	3.7-5.5
Nuclear	1200-2000	0.7-0.9	0.8-1	3.3-8

Table 7 Thermal plant data - current levels

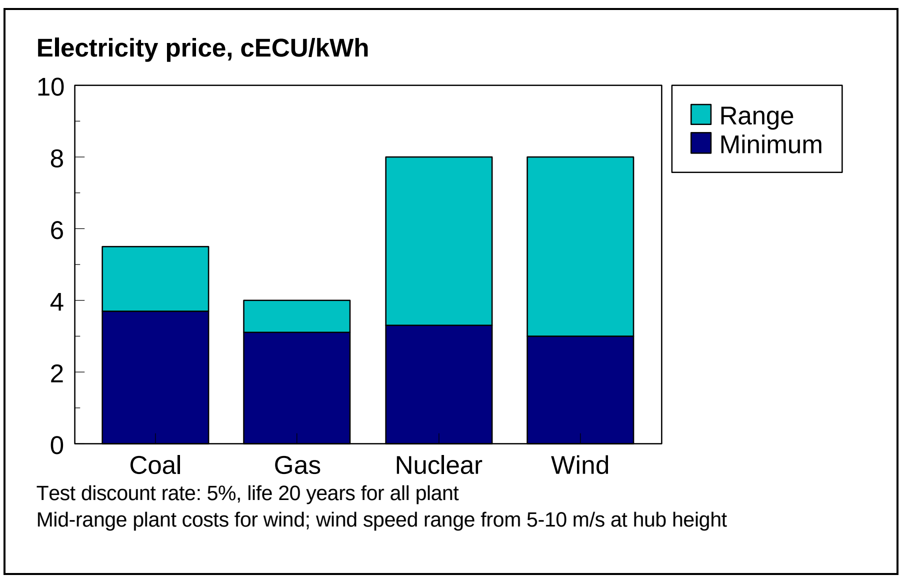


Figure 10 Current electricity prices

8 THE VALUE OF WIND ENERGY

Direct comparisons between the price of wind energy and of electricity from the thermal sources ignores the fact that, in many instances, renewable electricity-generating technologies deliver energy closer to consumer demand than centralised generation. It substitutes for electricity which has accrued a higher selling price than the generation costs of large thermal plant, due to its passage through the network. This rising level of "value" with reducing voltage is reflected in higher charges for customers connected at lower voltage levels. These concepts are illustrated in Figure 11, which includes typical selling prices for electricity at various stages in the system.

Small-scale generation of this kind is classified as "embedded". An alternative term for plant of this kind is "distributed generation" and there is a growing interest in the possible benefits, which may include reduced grid losses, a role in stabilising the supply in areas remote from generation and deferment of the need for main transmission reinforcement. It is argued that the value of the energy is greater than simple "generation substitution" when these benefits are taken into account. This issue is explored in more detail in Appendix D.

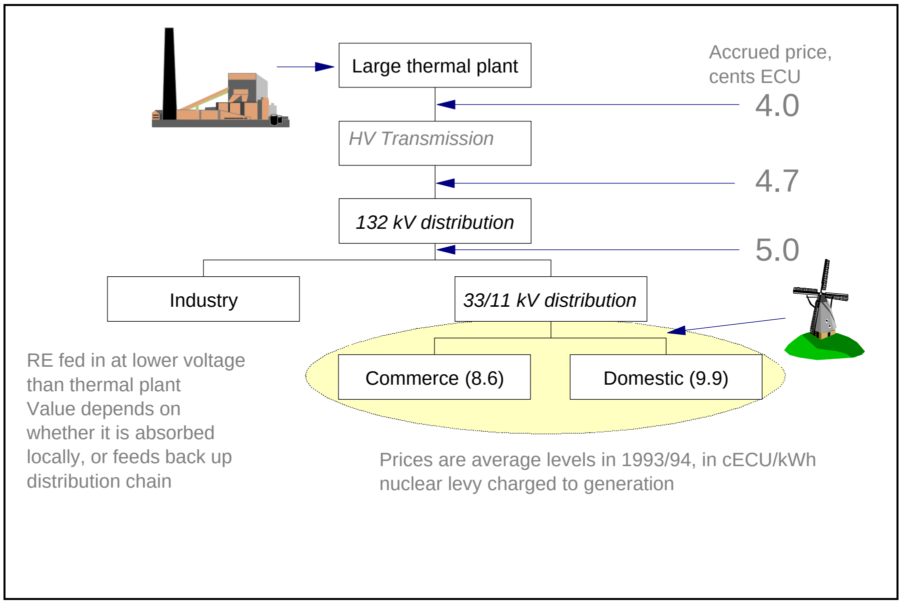


Figure 11 Electricity distribution and renewable energy

9 EXTERNAL COSTS

9.1 Introduction

The electricity prices quoted in Section 5 do not include the so-called "external costs" of electricity generation - those associated with damage to health and the environment. These are not borne by the electricity generator or consumer, and are not included in the price of electricity. External costs may be difficult to quantify accurately, and this is used as a reason for preserving the status quo, but there is increasing awareness that this is unsatisfactory.

Although there is general agreement as to the broad definition of external costs - costs attributable to an activity that are not borne by the party involved in that activity - there are widespread variations in defining the boundaries. There is an argument, for example, that the maintenance of petrol stocks for strategic reasons adds approximately one third to the price of fuel due to costs incurred in storage, extra transport and security. Therefore, this 'shadow' cost should be regarded as an "external cost" of oil.

9.2 Cost categories

External costs, or at least some elements, are difficult to quantify, but they are nonetheless real. If the enormous costs of cleaning up after the Chernobyl nuclear disaster had been taken into account when the plant was constructed, it clearly would never have been built. Arguments for the external costs attributable to oil fired generation range from supertanker spillages to a substantial proportion of western defence budgets. For simplification they can be divided into three broad categories (**23,24**).

- hidden costs borne by governments, including energy industry subsidies and research and development costs
- costs of the damage caused to health and the environment by emissions other than CO2
- the costs of global warming attributable to CO2 emissions

The second category is costs due to emissions which cause damage to the environment or to people. These include a wide variety of effects, including damage from acid rain and health damage from oxides of sulphur and nitrogen emitted from coal fired power stations. An EU-funded study has recently examined these in some detail (**25**). Other costs in this category are power industry accidents, whether they occur in coal mines, on offshore oil or gas rigs, or in nuclear plant. The probability of a nuclear accident in Western Europe might be extremely low, but should a catastrophic failure occur the costs would be undeniably huge. Multiplication of a number close to zero (the probability of a nuclear accident) by a number close to infinity (the cost of such an accident), does not necessarily give a meaningful result.

The third category is by far the largest: external costs due to greenhouse gas emissions which cause global warming - with all its associated effects. This is the most contentious area of the external costs debate. The range of estimates for the possible economic implications of global warming is huge. Costs associated with climate changes, flooding, changes in agricultural patterns and other effects all need to be taken into account.

9.3 External cost values

Despite the difficulties in assessing external costs there is a some measure of political agreement in the EU about the level of a carbon tax, and the EU's proposed carbon taxes would have reflected this rough consensus. This would eventually have added around 1.6 cECU/kWh to the price of coal-fired generation, 0.8 cECU/kWh to gas, and 0.7 cECU/kWh to nuclear. The latest proposals for energy taxation are more modest, and are not a good reflection of external costs.

10 FUTURE PRICE TRENDS

A number of factors are causing a steady fall in the cost of wind energy systems:-

- The trend towards larger wind turbines
- Falling infrastructure costs

- Possible reductions in the cost of raw materials

Manufactured items which are produced in quantity benefit from increased production, due to improved manufacturing and assembly techniques. The way in which costs fall as a depends on the product, and is a function of the relative inputs of material and labour. For wind turbines it has been estimated that the price is likely to fall by 8% for each doubling of production. Given that other factors, such as better understanding of wind loads and materials properties, also contribute to cost reduction, this figure may be improved. As wind turbines are relatively small in output - in power generation terms - the need for significant numbers of machines enhances their prospects for cost reduction.

The energy price trends shown in Figure 4 do not give any indication that the trend in price reductions is slackening. The recently-completed European Renewable Energy Study (TERES II) reaches a similar conclusion. It also expects that further R&D will enable technological advances to be made.
By 2020 capital costs are expected to be 50-75% of present levels, allowing financially viable wind energy production on high and medium wind regime sites. Data from the study, shown in Figure 12, indicate that wind may become one of the cheapest renewable energy sources**.**

Energy prices from the thermal sources are, however, subject to uncertainty. Demand for gas in Western Europe and the United States which will influence its price, as it is in relatively short supply. Coal is plentiful, but the growing demand from the third world - especially India and China - may raise the world coal price between now and the year 2000. Estimates for coal prices on the world market in 2000 range from 2.7 ECU/GJ to 3.5 ECU/GJ.

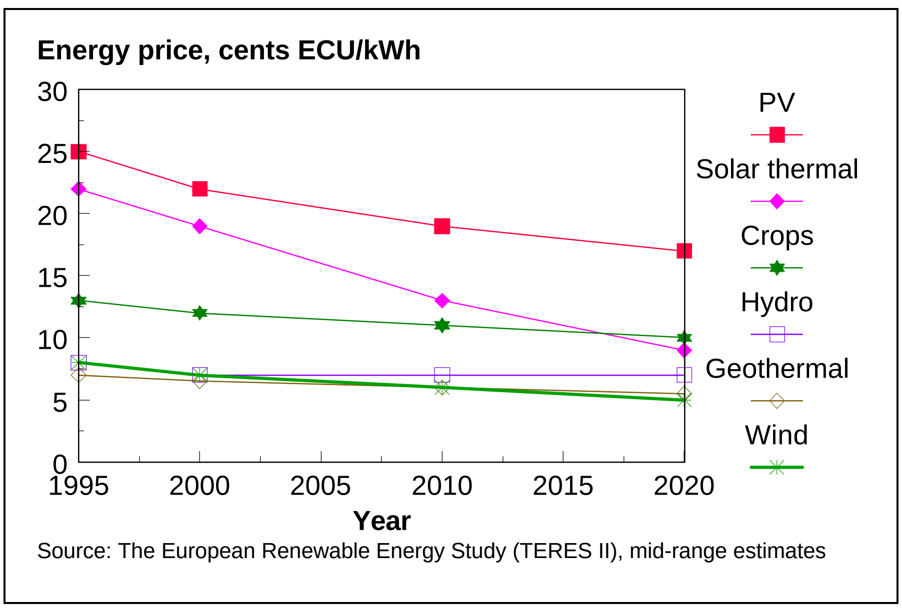


Figure 12 Forecasts for unit costs - centralised generation

With these provisos, Table 8 sets out energy price estimates for fossil sources for the year 2000. As there are a wide range of plant and other costs, two authoritative data sources, only, have been used; the UNIPEDE study **(4)**, and a recent EU assessment **(23).** The range of electricity prices has been derived after rebasing the UNIPEDE data to ECU1995. Two ranges are quoted:-

1. Using UNIPEDE central plant and fuel cost estimates, with 5% and 10% discount rates.
2. Taking into account, in addition, the spread of fuel cost estimates.

It must be emphasised that this Table adheres to the EU/UNIPEDE estimates and that a wider spread of price estimates would result from an examination of country-specific data.

As wind energy prices below 4 cECU/kWh have already been realised in the latest round of the UK NFFO**,** the prospects for wind energy are bright.

	Gas (CCGT)	**Coal**	**Nuclear**
Plant cost, 1992ECU/kW	694-754	1185-1293	1478-1740
Plant life, years	25	30	30
Fuel cost, cECU/kWh	3.3, +/- 0.6	1.9, +/- 0.3	0.8, +/- 0.1
O & M costs, cECU/kWh	0.4	0.7	0.8
1. Electricity price, cECU/kWh	5.0-5.5	4.4-5.6	4.0-5.7
2. Electricity price, cECU/kWh	4.4-6.1	4.1-5.9	3.9-5.8

Table 8 Thermal plant costs, year 2000

11 CONCLUSIONS

There is a very large variation of wind speeds, plant costs, test discount rates and other factors which influence wind energy prices across the European Union. Currently, an average EU-wide installed cost of 1000 ECU/kW may be taken as a typical value. German plant costs are slightly higher and Danish levels are slightly lower. A direct comparison between wind energy prices and those of thermal plant is misleading, as wind has lower external costs and often has a higher value. Nevertheless, wind becomes competitive with gas at the 5% discount rate, if both use amortisation periods of 20 years; at the 10%, gas is cheaper. Given that wind prices are falling, its competitive position is expected to improve.

In practice wind speeds vary widely across the EU, and wind prices at sites with winds higher than 6.5 m/s will clearly be lower. When the external costs of other fuel sources and system benefits of wind are taken into account, it is clear that wind's competitive position is becoming ever stronger.

More specific conclusions must be country-specific. The German wind prices shown in Figure 9, for example, must be set alongside the high price of generation from coal (there are very few gas-fired generation plant), and the massive subsidy given to the coal industry. As Danish utilities use discount rates around 6%, this works in favour of wind energy and several Danish studies have shown that the costs are similar to those of thermal plant. In Britain, however, gas prices are low, yielding low generation prices, but wind prices, based on the latest NFFO bids, are only slightly higher, due to the high wind speeds.

The key conclusions may therefore be summarised:-

- Wind plant costs have been falling steadily and this trend is likely to continue.
- Wind energy prices are falling faster, as machines become more reliable and efficient.

- No single figure can be assigned to price of wind energy, as wind speeds, interest rates, amortisation periods and plant costs vary across the EU, but -
- On best sites, current wind prices are within ranges quoted for thermal plant.
- External costs of thermal plant need to be taken into account when making comparisons with wind energy prices. Some external costs, like the cost of coal support in Germany, are irrefutable. Others more difficult to quantify, but nonetheless real.
- Wind energy must also be credited with additional value, as it is usually injected into low voltage distribution networks, enabling utilities to save on transmission and other costs.
- Offshore wind energy prices are moving down rapidly.
- There is considerable scope for future price reductions, supported by several studies.

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APPENDIX A

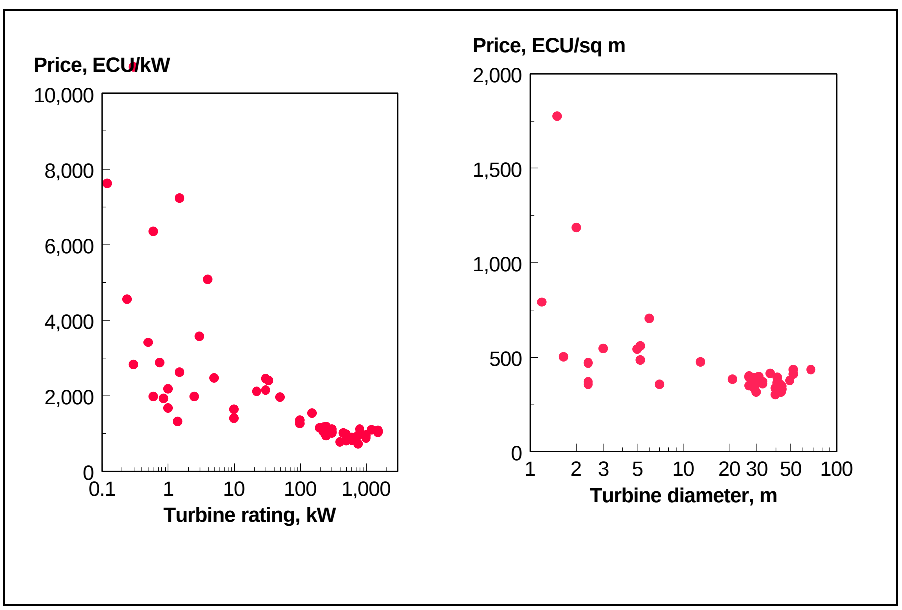
WIND PRICE SENSITIVITIES

A1 COST/SIZE TRENDS

A1.1 Introduction

A number of analyses of wind energy prices have shown that wind turbine economics improve with increase of size. Rehfeldt et al, for example **(1)**, show that the price per annual kWh falls by over 25% as rotor diameter increases from the 16/22 m range to the 32/45 m range. The Danish data plotted in Figure 3 shows a similar trend.

A study of wind turbine prices, however, shows that wind turbine prices fall with increasing size up to a certain point beyond which the price rises. The reasons for this trend have been explored in some detail (2). The very small machines cannot easily make the best use of material; bearings and generators tend to assume a higher proportion of the cost than at the larger scales. At the very large sizes, however, the influence of weight - which must inevitably tend to increase as the cube of the size - may make the economics less attractive. These trends can be seen in Figures A1 and A2. Figure A1 shows prices, in ECU/kW plotted as a function of turbine rating; this graph exhibits more scatter than the analysis in terms of ECU/sq.m against diameter (Figure A2). Despite the scatter on both graphs the overall trends are clear. At the 1 kW size, prices are around 2500 ECU/kW, falling to around 800 ECU/kW around the 500 kW region. A more detailed examination of larger machines shows that prices move upwards from a minimum value around 350 ECU/sq m as size increases towards 70 m diameter (Figure A3). The "most economic size" has changed over the years and may continue to change, but the fundamental design laws mean that the price - size curve will always tend to have a similar form.



Figures A1 and A2 German wind turbine prices

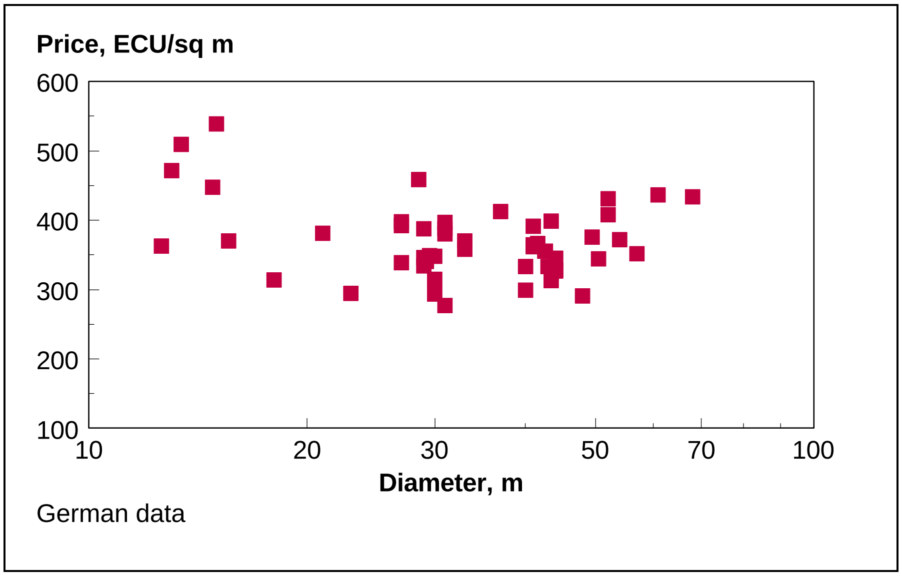


Figure A3 Price and diameter - larger wind turbines

A1.2 Balance of plant costs

Although wind turbine prices may increase at the large size ranges, there are nevertheless sound reasons for pursuing the development of such machines. A number of items in the "balance of plant" costs decrease with size of machine and/or machine numbers such as:-

- Foundation costs
- Electrical interconnection costs
- Access tracks

The way in which foundation costs decrease with increasing size is illustrated in Figure A4. Analytical studies have considered these issues in more detail and shown that the contribution of balance of plant costs to overall energy costs can be reduced by around 25% by moving from machines of the 300 kW size range to 1 MW size machines.

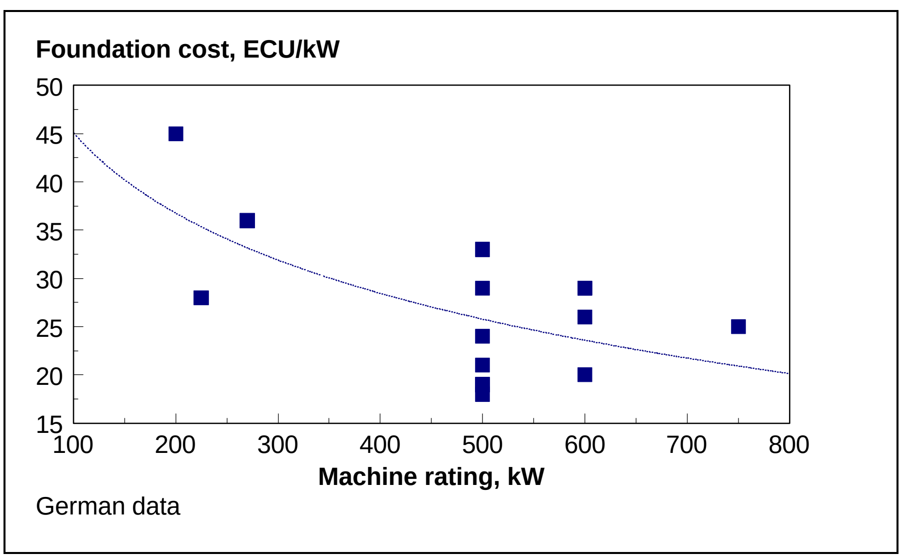


Figure A4 Foundation costs

A1.3 Operational Costs

Operational costs also fall with increase of turbine size. Analysis of data from German wind installations (**3**) shows that the price of insurance and guarantees both halve, approximately as ratings increase from 200 to 600 kW (figure A5). Total costs fall from around 38 ECU/kW/yr at the 200 kW size to around 15 ECU/kW/yr at 600 kW.

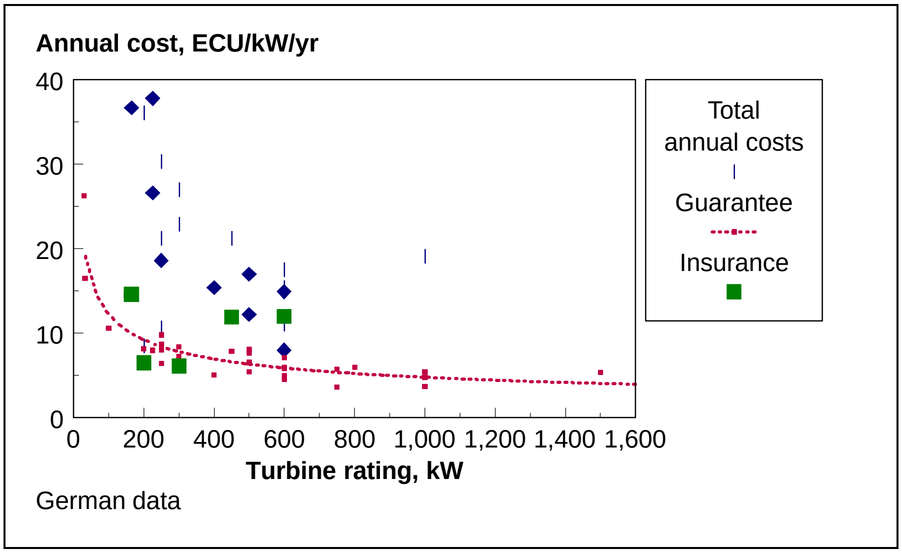


Figure A5 Cost of operations

A2 PRICE AND MACHINE NUMBERS

Wind farm prices decrease weakly with increasing numbers of machines. (Figure A6). Prices average around 1300 ECU/kW with one machine, falling below 1200 ECU/kW with 20 machines. Although conventional wisdom indicates that this trend should be stronger there are so many factors which influence wind farm prices that frequently the trend is obscured. This does not invalidate the general hypothesis that, at a given site, construction of a wind farm rather than a single machine will generally be the cheaper option **(4)**.

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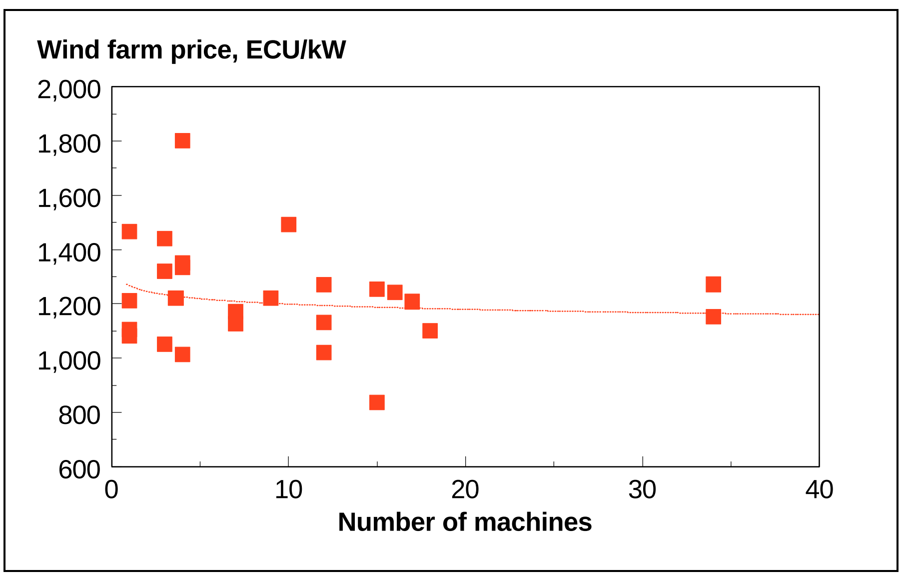

Figure A6 Effect of numbers on wind farm price

A3 PRICE CHANGES OVER TIME

Data from German and British wind farms confirms the Danish trends discussed in Section 3. British prices fell by about 35% and German prices by about 16%., as shown in Figure A7. Given the strong trend, discussed in Section 3, for turbine prices to fall, a more significant rate of decrease may have been expected. However, the more accessible - and cheaper - sites in Germany were used up in the early years of the wind programme and later construction has had to use more expensive sites.

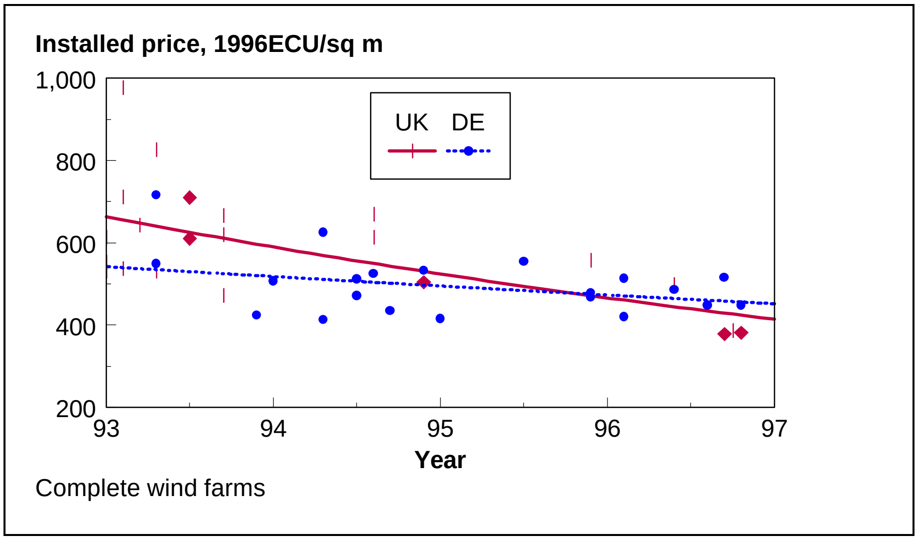

Figure A7 Price changes with time

A4 PRICE AND YIELD

The link between for prices and energy yields is examined in Figure A8 and a weak, but discernible increase of price with yield is evident, in Britain and Germany. This is probably due to the fact that the higher yields in Germany may be found at coastal sites, where foundation costs are frequently higher due to the necessity of piling into the silt. A further factor which may influence this correlation is that tall towers are often deployed to give access to higher wind speeds, but at increased turbine cost. In Britain, the high wind speed sites tend to be in remote areas, with higher construction costs.

Prices have been correlated with energy yield, as wind speed data are not always available or reliable. However 400 kWh/sq m corresponds to around 4.5 m/s (installed cost around 400 ECU/sq m) and 1300 kWh/sq m is around 8 m/s (installed cost around 550 ECU/sq m).

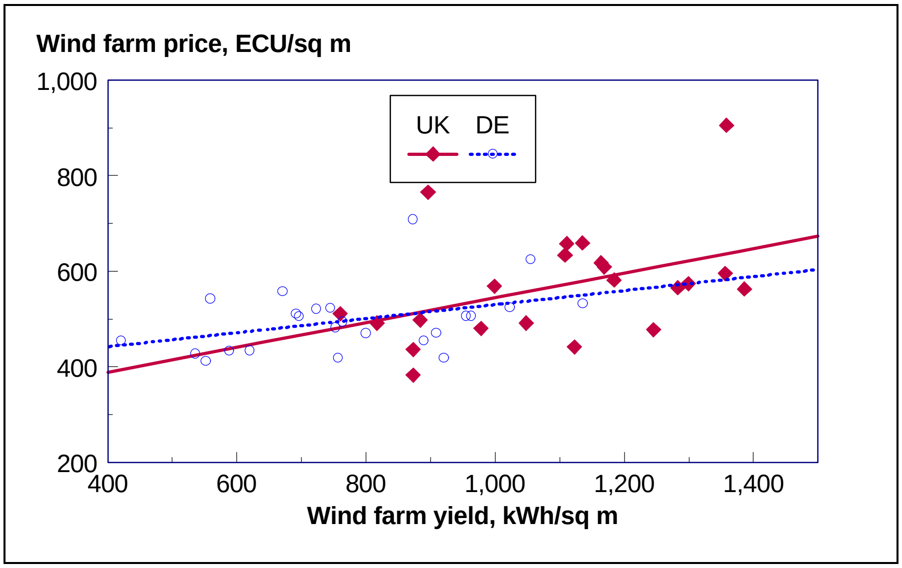

Figure A8 Wind farm costs and yield

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APPENDIX B

OFFSHORE WIND ENERGY

B1 INTRODUCTION

Offshore wind has the potential to deliver substantial quantities of energy - at a price which is cheaper than most of the other renewable energies, but not yet competitive with the conventional thermal sources - nor with onshore wind. Offshore wind energy has the added attraction that it has minimal environmental effects and, broadly speaking, the best European resources are reasonably well located relative to the centres of electricity demand.

An additional attraction of offshore wind power is that wind speeds are generally higher offshore than on land, although the upland regions of the British Isles, Italy and Greece, do yield higher speeds. In the UK, for example, onshore winds at hilltop sites range up to 9 m/s at hub height - higher in some instances - whereas offshore winds at, say, 5 km from the East Coast (where the utility PowerGen is contemplating a wind farm) are around 8-8.5 m/s. Offshore wind power is therefore, most attractive in locations such as Denmark and the Netherlands where pressure on land is acute and where windy hill top sites are simply not available. In these areas offshore winds - which increase with distance from land - may be 0.5 to 1 m/s higher than onshore, depending on the distance offshore.

B2 OPERATIONAL EXPERIENCE AND ECONOMICS

A number of factors combine to push up the cost of offshore wind farms relative to their onshore equivalents:-

- the cost of the cable connection from the wind farm to the shore.
- the need for more expensive foundations, where a number of options have been examined:-
    - gravity-based structures, simple, but heavy
    - piled structures
    - tethered, floating structures, which support individual turbines or groups

- operation and maintenance costs are increased with the risk of lower availability due to difficulties in obtaining access to the wind turbines during bad weather.
- the need to "marinise" the wind turbines, to protect them from the corrosive influence of salt spray

Several offshore wind farms have now been built, so it is possible to assess the economics in the light of operational experience. To do so, data from the two experimental Danish installations, Vindeby and Tuno Knob (**1**), may be compared, and set alongside other recent cost assessments, including the pilot Dutch farm in the Ijselmeer (**2**). Table B1 summarises the principal operational data for these early wind farms together with a proposed installation by PowerGen off the East coast of England (**3**), and recent proposals for large farms off the Coast of the Netherlands and Denmark (**2,4**).
Although the cost of the Vindeby wind farm was 85% higher than the cost of an onshore installation the anticipated energy yield was 20% higher. (Production statistics show that the

energy production is higher than expectations, so concerns about lower availability offshore - due to problems of access - have not been realised).

PowerGen's proposals for Scroby Sands were for a much larger wind farm, comprising 25 63m 1.5 MW wind turbines. The site is 3 km off the Norfolk coast near Yarmouth and the initial estimate of the project was around 44 MECU, bringing costs per annual megawatt hour to about half that of Vindeby - due partly to continuing maturity of the industry and partly to the use of larger machines.

Location	Date	Turbines	Capacity	Wind	Output	Cost		
		No.*kW	MW	m/s	GWh	MECU	ECU/MWh	ECU/kW
Vindeby, DK	1991	11x 450	4.95	7.9*	11.2	9.6	857	1939
(Comparable onshore farm)				7.2*	10	5.3	530	1071
IJsselmeer, NL	1994	4 x 500	2		3.8	3.8	1000	1900
Tuno, DK	1995	1 0 x 500	5	7.4*	12.5	10.6	848	2120
Gotland, SW	1997	4 x 500	2			2.8		1400
Scroby, UK	Planned	25 x 1500	37.5	8.2*	102*	44	429*	1173
IJmuiden, NL	Planned	100 x 1000	100		275	225	818	2250
Laeso, DK	Planned	400 x 1500	600		2028	934	461	1560
*Author's estimate								

Table B.1 Offshore wind farm performance and costs

B3 FUTURE OFFSHORE TRENDS

The PowerGen project did not secure a contract in the competitive bidding for the Non-fossil Fuel Obligation (NFFO), but two other offshore proposals did succeed. One is a two-machine cluster, one kilometre from Blyth, in Northumberland, the second a 30 MW project off Clacton, in Essex. No details of costs are available, but one may have a grant from the EU demonstration programme.

The two major utilities, Elkraft and Elsam, have recently announced their intention to build 750 MW of offshore wind, and there are also plans for a 30/40 MW scheme near Copenhagen. Two major utilities in the North of Holland, ENW and NUON have proposed a windfarm in the shallow waters along the 35 kilometre long "Afsluitdijk" between the Provinces of Friesland and Noordholland. The line of 57 MW-sized turbines (two-bladed 60/1.750) will be sited at 500 metres from the dike and 500 metres apart from each other. The project is budgeted at 114 MECU (about 875 ECU/sq m rotor area) and could be build within three years.

An analysis of energy prices has recently been carried out for the Danish utilities (5). This showed that the use of larger wind turbines - up to 1500 kW rated output - would realise substantial savings. Assuming a wind farm is sited around 6 km from the coast, in a water depth of 5-6 m, the electricity price may be expected to fall from around 6 cECU/kWh (at Tuno) to around 3.8 cECU/kWh.

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3 Norfolk offshore wind farm takes off. Modern Power Systems, September 1996.

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5 Morthorst, PE, and Schleisner, L, 1997, Offshore wind turbines - wishful thinking or economic reality? Proc EWEC97, Dublin, 6-9 October. European Wind Energy Association.

APPENDIX C

EXTERNAL COSTS

C1 INTRODUCTION

The so-called "external costs" of electricity generation - those associated with damage to health and the environment - are currently borne by those who must rectify this damage (not usually the polluter); they are not made transparent in the market price of electricity. The fact that external costs are difficult to quantify accurately is used an argument for preserving the status quo, but there is increasing awareness that this is unsatisfactory. This section draws upon a review undertaken for the journal *Windpower Monthly* **(1)**.

C2 KEY ISSUES

Although there is general agreement as to the broad definition of external costs - costs attributable to an activity that are not borne by the party involved in that activity - there are widespread variations in defining the boundaries. There is an argument, for example, that a substantial proportion of Western defence budgets should be regarded as an "external cost" of oil - for fairly obvious reasons.

External costs - or at least some - may be difficult to quantify, but they are real. If the enormous costs of the clean-up operation after the Chernobyl nuclear disaster had been taken into account when the plant was constructed, it is unlikely it would have been built. The task facing energy policy makers is how best to go about the job of reducing pollution in electricity generation when, in most countries, external costs are not reflected in the market price of the end product. If they were, fossil fuel and nuclear energy prices would rise, making wind energy one of the cheapest technologies.

In Europe, regulation of the fuel mix for electricity generation, as a way of reducing pollution has not been generally accepted. The problem is how to include external costs as an element of competitive electricity markets - without interfering with market forces. Not all governments are following this route, but there is a clear trend in that direction.

At one end of the spectrum is Denmark, determined to bring about a 20% cut in carbon dioxide emissions. It has an efficient distribution system and plenty of renewables - promoted by carefully designed energy taxes. Britain, at the other end of the spectrum - at least until the recent change of government - had an unambitious target for carbon dioxide reductions, with consideration of external costs sidelined. There are now indications that this may change.

C3 COST CATEGORIES

There are widespread variations in defining the boundaries. Arguments for the external costs attributable to oil fired generation range from supertanker spillages to a substantial proportion of western defence budgets. For simplification, however, they can be divided into three broad categories.

- hidden costs borne by governments

- costs of the damage caused to health and the environment by emissions other than CO2
- the costs of global warming attributable to CO2 emissions

The first category includes the cost of regulatory bodies and pollution inspectorates (generally small) and the cost of energy industry subsidies and research and development programmes. These are larger. In the analysis of external costs published in 1988, Hohmeyer **(2)** calculated that support to the German coal industry added DEM 0.002/kWh to the price of electricity. He also assigned a cost of DEM 0.0235/kWh for nuclear R&D, compared to around DEM 0.004 DM/kWh for wind.

The second category is costs due to emissions which cause damage to the environment or to people. These include a wide variety of effects, including damage from acid rain and health damage from oxides of sulphur and nitrogen emitted from coal fired power stations. In a recently released European study, ExternE **(3)**, the costs of damage to health were estimated by calculating the loss of earnings and costs of hospitalisation of people susceptible to respiratory diseases.

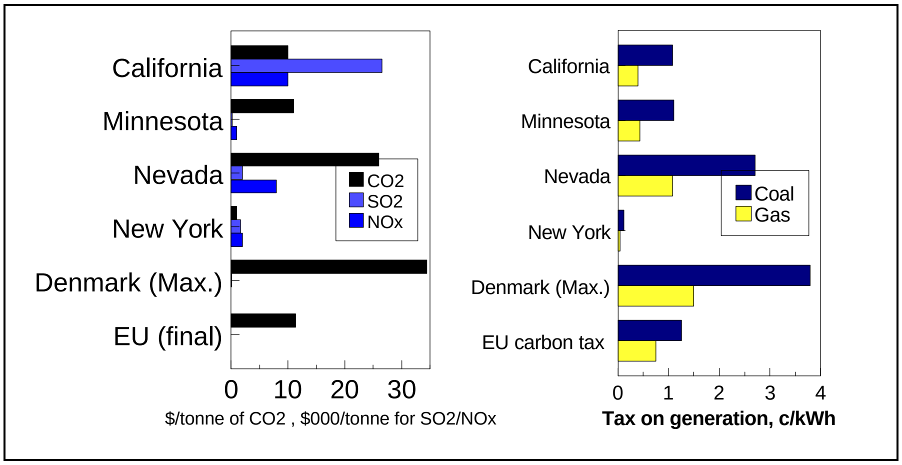
Other costs in the damage and health category are power industry accidents, whether they occur in coal mines, on offshore oil or gas rigs, or in nuclear plant. The probability of a nuclear accident in Western Europe might be extremely low, but should a catastrophic failure occur the costs would be undeniably huge. Multiplication of a number close to zero (the probability of a nuclear accident) by a number close to infinity (the cost of such an accident), does not necessarily give a meaningful result.

The third category is by far the largest: external costs due to greenhouse gas emissions which cause global warming. This is the most contentious area of the external costs debate. The range of estimates for the possible economic implications of global warming is huge. Costs associated with climate changes, flooding, changes in agricultural patterns and other effects all need to be taken into account.

C4 PRICE ESTIMATES

Hohmeyer **(2),** ExternE **(3),** and others looked at damage potentials on health and the environment, assigning a cost penalty to each generating technology, depending on the fuel. This approach enables the difference in external costs between, say, coal and wind, to be easily compared. Another approach calculates costs per pollutant, as different fuels generate different amounts of pollutant. Typically these penalties, as proposed by some American states, are around $10/tonne for CO2, and up to $25,000/tonne for SO2 (Figure C1). Since the quantities of each pollutant, per kWh, are known for each fuel, these costs enable calculation of the external cost of each unit of electricity. Coal-fired generation produces the most pollutants - about 1 kg of CO2 per kWh, plus SO2 and other pollutants. It therefore attracts the highest penalties (Figure C2).

Despite the wide variety of approaches, the external cost assigned to coal-fired generation is often reckoned to add about 1 cent (US)/kWh to each kWh. Gas, on the other hand attracts a lower penalty - around half this figure.



Figures C1 and C2 Taxes on emissions and fossil generation

C5 MARKET MECHANISMS

Once monetary values are assigned to the extra cost of energy from differing technologies, the next step is to find a mechanism for "internalising" them in market prices. There is, however, a debate on the best way to apply external costs - if at all. At one end of the spectrum are the free marketeers, who argue against any interference; at the other are those who feel that there are imbalances in energy pricing which need to be rectified. The Netherlands and Denmark, amongst others, have acted and introduced so-called carbon taxes.

The European Union's original proposals for a carbon tax would have altered the balance between coal, gas, nuclear and wind significantly, adding around 1.5 cECU/kWh to coal-fired generation prices, and 0.8 cECU/kWh for nuclear. The levy included an "energy" element as well as a "carbon" component, which is why nuclear is penalised. The tax was intended to be "fiscally neutral", with tax revenue supposedly to lead to tax reductions elsewhere; reliefs were proposed for energy-intensive industries. Several EU states were concerned that higher energy taxes would reduce the competitiveness of their industries in global markets.

Nevertheless, some EU states have gone ahead and introduced carbon taxes. Denmark has recently implemented a wide range of measures aimed at encouraging the energy industries to become more efficient and to reduce harmful emissions. The taxes are applied to fuels and to electricity, but also focus on consumption, with space heating, for example, attracting the highest tax rates.

An alternative approach to the problem of reflecting external costs - and one which possibly causes less economic disturbance - is to assign the renewable energies "environmental credits." This is the basis of the 1.6 cent "production tax credit" currently available to wind power in the United States. This has the merit of simplicity and has a marginal effect on energy costs, but it is not a true integration of external costs into market prices. The taxpayer pays, not the electricity consumer.

C6 INTEGRATED RESOURCE PLANNING

A third approach - favoured by many American states - is to use "integrated resource planning" (IRP) to assess future generating plant needs. The beauty of IRP is that, in complying with government mandates to consider all energy supply options, the regulatory body simply assumes that external costs are to be applied, without actually imposing them. This approach does away with the need to agonise over how to calculate the monetary value of pollution in electricity generation. It also helps to ensure that power plants are built in the right place and that the electricity network operates efficiently. The result is a competitive market operating under guidelines aimed at long term economic responsibility.

Recent studies in California and elsewhere, however, indicate that the result of this approach is simply to shift the utility plant mixes in favour of gas, which is currently cheap and has low external costs. Renewables profit, but the additional market share remains relatively small. It is important to remember, however, that gas is unlikely to remain so cheap indefinitely.

C7 EXTERNAL COSTS of RENEWABLE ENERGIES

No-one claims that renewable energies have zero external costs. The recent EU study, for example, examined the external costs of wind energy under nine headings (nv: not valued):-

1. Noise
2. Visual Intrusion
3. Accidents during manufacture and operation
4. Accidents to public
5. Impacts wind turbines on birds (nv)
6. Impacts on local ecosystems (nv)
7. Electro-magnetic interference (nv)
8. Acid rain damage - from energy used in construction in case of wind
9. Global warming effects

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The range of cost estimates - for two specific British sites - lay in the range 0.2-0.4 cECU/kWh. This is consistent with other studies, which generally show lower external costs for wind than either PV or biomass, although all are small. The analysis was very thorough and included estimates of external costs incurred during the manufacturing processes, as well as operation of the plant. Nevertheless, the overall conclusion from the EU study was that the highest estimate of external costs for wind was below the minimum estimate of the external costs for coal. Excluding global warming, the latter were between 0.5 and 1.5 cECU/kWh.

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APPENDIX D

THE VALUE OF WIND ENERGY

D1 INTRODUCTION

Most utility studies which have studied the effect of installing wind plant on interconnected networks have shown that operation of the system is unaffected by the variability of wind - provided the amounts of wind energy on the system are modest. "Modest" in this context implies energy penetrations below about 10%.

Early studies assigned a fuel-saving value, only, to wind energy. More recently, it has been argued that wind energy should be assigned a higher value as it is injected into low voltage distribution networks and does not incur high voltage transmission costs and resistive losses. This hypothesis is implicitly recognised in some National remuneration schemes - such as those operated in Denmark and Germany - where wind energy is paid a proportion of consumer selling prices. Although studies in America and elsewhere, point to the fact that renewable energy may have a high value in certain locations, this point is generally not accepted within EU utilities, most of whom continue to assign wind energy a value based on its fuel saving capability.

D2 THE CONCEPT OF EMBEDDED GENERATION

In many instances renewable electricity-generating technologies deliver energy closer to consumer demand than centralised generation. It substitutes for electricity which has accrued a higher selling price than the generation costs of large thermal plant, due to its passage through the network. This rising level of "value" with reducing voltage is reflected in higher charges for customers connected at lower voltage levels. These concepts are illustrated in Figure 12, which includes typical selling prices for electricity at various stages in the UK system.

Small-scale generation of this kind is classified as "embedded". In England and Wales, for example, there are currently some 1500 MW of embedded generation although most of this is not renewable plant. An alternative term for plant of this kind is "distributed generation" and there is a growing interest in the possible benefits, which include system support in areas remote from generation and deferment of the need for main transmission reinforcement. It is argued that the value of the energy is greater than simple "generation substitution" when these benefits are taken into account.

D3 BACKGROUND TO ELECTRICITY PRICING

The cost, price, and hence the value of electricity varies on a geographical basis. Above-average costs are incurred when energy has to be transmitted long distances from the generating plant. The need to supply remote locations increases the costs of the distribution network and, in addition, electrical losses are incurred in feeding the energy to the extremities of the system.

Electricity utilities do not attempt to ascribe exact costs to account for all geographical and temporal factors. Tariffs build in cost averaging so that blocks of consumers with similar requirements and locations pay similar rates. A further factor which complicates an analysis of value is that accounting procedures vary and political considerations may be imposed in pursuit of particular objectives. These tend to distort accurate assessments of value. Examples of such political overlays are requirements by many Governments that all domestic consumers should be treated equally.

D4 SYSTEM COSTS

As part of an EU-funded study (1), an analysis of the cash flows through the electricity network in England and Wales has been carried out to aid a study of value. The data are being compared with information from tariffs, and with other case studies in Europe and the United States. The cash flow data enable average levels of electricity price to be established at key points in the distribution chain:-
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- At the busbars of large thermal plant
- At exit from the high voltage transmission system
- at delivery to the consumer

Conventional terminology assigns three stages between the production of electricity and its delivery to the consumer:-

- generation
- high voltage transmission (often abbreviated to "transmission")
- distribution

For each of these stages of in the supply chain, costs can be allocated under 4 headings:-

- <u>Fuel,</u> (fuel cost purchases for generators and power losses in transmission and distribution)
- <u>Operating,</u> reflecting all operating costs including overheads
- <u>Depreciation</u> of capital assets
- <u>Profit</u> on a historic cost basis

The cash flow analysis was carried out for 1993/94 as additional data were available from privatisation prospectuses to aid the segregation of costs. Costs in nominal money vales were very similar in 1996/97.

The results of the cashflow analysis are shown in Summary form in Table D1.

	Generation	Control	Transmission	Distribution	Supply	TOTAL
FUEL	2.03	0	0.08	0.31	0	2.42
OPERATING	1.28	0.14	0.11	0.8	0.26	2.59
DEPRECIATION	0.35	0.01	0.16	0.42	0.01	0.95
PROFIT	0.35	0.03	0.17	0.58	0.13	1.26
TOTAL	4.01	0.18	0.52	2.11	0.4	7.22

Table D1 UK electricity price breakdown (cents ECU/kWh)

Although the constituent elements of electricity price, tabulated in Table D1, define its "value" at any given point in the system - in average terms - it does not follow that electricity which is injected at that same point will be credited with that same value by the generator or utility. A brief summary of current attitudes to value follows:-

- **Fuel** - most studies accept that fuel savings are a component of the value of Renewable Energy. With the intermittent sources, the value declines as the amount of intermittent capacity increases, for reasons discussed in Section D5.
- **Operating Costs** - These include "Fixed" and "Variable" components. The variable costs of generation are part of the value of RE, but the variable costs of transmission and distribution are more contentious issues. Acceptance of the Fixed component of these costs as a component of value depends on whether it is accepted that RE, particularly the intermittent sources has a "capacity credit". This is considered in more detail in Section D6.
- **Depreciation** - the crucial point is whether the introduction of RE on to a system enables plant savings to be made (section D6). Most studies which have addressed generation plant savings, but more recent work addresses transmission and distribution savings.
- **Profit** - The question of profit as an element of value has not explicitly been addressed. In a deregulated system, where no single generator or distributor has exclusive rights, it would seem valid to allow its inclusion, at least partially, in value assessments.

The price elements shown in Table D1 apply to the system as a whole. Regional variations occur for many reasons, primarily the proximity of a locality to sources of generation.

The average delivered price of energy from the HV network in England was 4.7 cECU/kWh in 1993/94. Beyond this point, savings realised by RE plant such as wind farms will vary, but an average level has been estimated by assuming that one-half of the distribution losses are avoided. However, for every unit of electricity which passes through the distribution system, a mark-up (profit) of 0.6 cECU/kWh is added, and it appears both logical and fair that this profit should not remain wholly with the distributor. If half this profit element is assigned to the wind energy generator then an average value of wind energy on the English system is 5.6 cECU/kWh. Regional variations in prices mean this level may lie between 5 and 6.4 cECU/kWh.

At the European level, comparisons of English cost levels with those elsewhere indicates that this range of values is relevant to most mainland systems.

It must be emphasised that these are average values and particular installations may have higher or lower values, depending on their location within the network.

Particular technologies may also have higher or lower value, depending on their seasonal and diurnal generation profiles and the match (or otherwise) with demand. Assessments for wind and solar in England, based on typical seasonal variations, indicate that wind energy's fuel saving value is 3% higher than the mean and that of solar is 5% below the mean. The principal reason for temporal variations in electricity cost is the changing demand on the system. As the load rises, more plant must be brought into use and, as this plant does not operate at base load, its operating costs are higher.

D5 EXTRA OPERATING COSTS

Operation of European supply systems with small amounts of wind plant poses no problems whatsoever. The systems are able to cope with the sudden loss of a large generator or the effects of thunderstorms (which can cause trips on the transmission network). Nevertheless, increasing amounts of wind might require a change in operating procedures and a preliminary assessment of the extra operating costs has recently been made **(2)**, updating an earlier study for England and Wales. The costs arise if additional plant needs to be held on part load to compensate for possible fluctuations in the level of wind generation.

The additional part-loading costs can be derived by noting that plant which is part-loaded operates at a lower efficiency and that the part-load energy loss is equivalent to 15% of the full load heat rate (**3**). This energy penalty, in turn, can be converted to a monetary value by assuming an appropriate coal cost. Using a level of 1.55 ECU/GJ - roughly the delivered cost, based on the world market price - the extra costs as a function of energy penetration may be derived. (Figure D1). This shows the extra cost is below about 0.05 cECU/kWh with 1% energy penetration, rising to about 0.1 cECU/kWh at 10% penetration

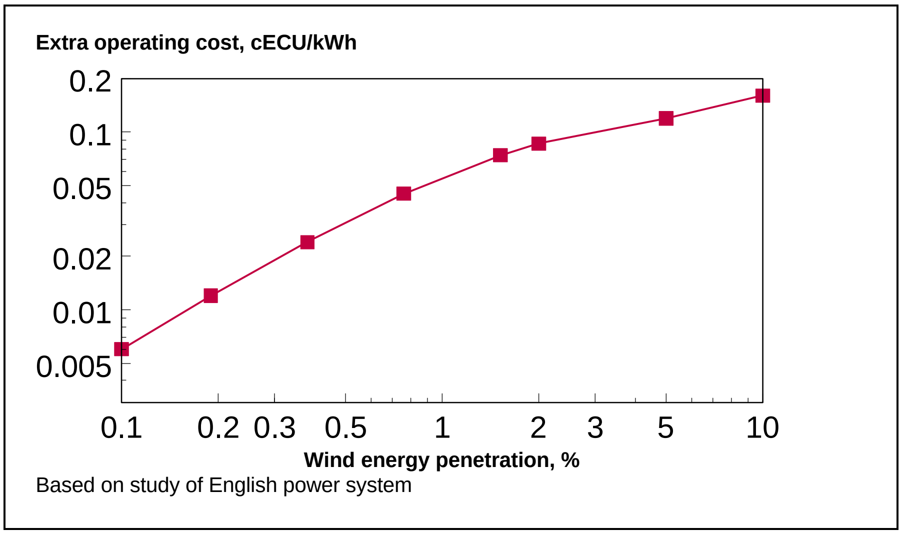

Figure D1 Extra operating costs incurred with rising wind energy use

D6 CAPACITY CREDITS

An important element of value is the capacity credit of renewable plant. If plant has a capacity credit, then some of the depreciation cost can be included in the value assessment.

The capacity credit of power plant may be defined, in general terms, as a measure of the ability of the plant to contribute to peak demands of a power system. Utilities quantify this in different ways, so numerical values of capacity credit are not necessarily comparable.

Data from ten utilities who examined the impact of wind on utility networks for the European Commission study have been collated (4) and compared to determine underlying patterns in assessments of capacity credits. It was found that:-

- Capacity credits increase with annual capacity factor

- Although capacity credits are often derived from summations of LOLP over a full year, the result is very strongly influenced by values near the time of peak demand. (Since LOLP decreases very rapidly away from the peak). It follows that -
- An examination of the long-term expectation of generation at times of peak demand enables credits to be established with reasonable accuracy

It should be noted, however, that the overall value of capacity to an electricity network is usually modest. The EC-funded studies yielded a range between 5 and 38% of generation costs. The accounts of the UK generators show that depreciation accounts for about 10% of the selling price.

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European Commission
Directorate-General for Energy

WIND ENERGY - THE FACTS

Volume 3

INDUSTRY AND EMPLOYMENT

EXECUTIVE SUMMARY

Introduction

The wind energy industry has grown in capacity and maturity very rapidly over the last 15 years. It has created a new means of generating clean electricity, new jobs and new factories. This volume explores the industrial aspects of the development and sets out the conditions required to ensure that the industry continues to realise its potential in an effective and economic fashion.

Jobs

Under current European market conditions the installation of each 1 MW of wind power creates jobs for between 15 and 19 people. In more labour intensive parts of the world this figure may double. Further jobs will also be created, including jobs in operation, service and maintenance. The timetable for this development is set out in the table below.

Year	EWEA goals MW	Jobs created Man years
1996	3,500	
2000	8,000	72,000
2010	40,000	512,000
2020	100,000	960,000

Anatomy of the industry

As is common for a new area of activity the wind energy industry started with a large number of small players. The development of the technology and the market have gone hand in hand. Over the last five years there has been a rationalisation and reduction of the number of participants and a strengthening of the capital base which supports them. There has also been a move towards vertical integration of both manufacture and development of wind farms. Wind energy is a growth area and is considered as such by the financial sector. The main players are becoming established with utilities and members of the conventional power industry are taking a keen interest in wind.

As markets distant from the home manufacturing bases are established technology transfer has been successfully implemented to provide local facilities. This approach is expected to find widespread use in the future.

Offshore wind energy provides opportunities for the development of a whole new branch of technology within the wind energy industry which will involve companies from the established offshore energy field. It will provide a major new market with negligible effect on the environment.

Conclusions

The wind industry is developing rapidly. It is moving from the pioneering stage in both technological and commercial terms. As the technology matures, the cost reduces and the market expands. The industry is being recognised as an exciting and vibrant entity and major players who have hitherto been reticent about identifying themselves with renewable energy are now keen to join. This move is to be welcomed and is a clear sign that, in commercial terms, wind is just one of the alternatives along with coal, oil and gas - part of the energy industry. Given appropriate market conditions wind energy will provide hundreds of thousands of new jobs in an exciting clean industry.

TABLE OF CONTENTS

1 EUROPEAN WIND INDUSTRY IN A GLOBAL CONTEXT

1.1 Brief historical review

A more detailed introduction to the history of the market development is provided in Volume 5. A brief summary is reproduced here.

The first large market to appear was in California, USA. The growth of this market stimulated the development of wind technology in many other countries. Newly established manufacturers of wind turbines from Denmark, the UK, Germany, Japan and the Netherlands shared the market in California with several US companies. About 14-15,000 wind turbines were installed within very few years. Nearly 60 per cent of the wind turbines came from European manufacturers (mainly Denmark) and during this period of time the size of the average wind turbine increased from 55 kW to 100 kW. Many different designs were installed and tested during these years and the industry gained a lot of experience. The market in California demanded a maximum return from available sites and led to larger scale projects which we now know as "wind farms".

In the years from 1986-1990 the market in California declined causing major financial difficulties in the wind industry. The market had grown very fast and many companies had been too reliant on it. Many companies went bankrupt and disappeared, while others were reconstructed with new capital The numbers of manufacturers had been reduced and so had the many design concepts. The simple Danish, 3-bladed, stall regulated design survived and was up-scaled to provide more cost effective 250 kW units. Pitch regulated wind turbines became more prevalent. These technological developments suddenly made it economically feasible to install wind power in many new markets and this was the beginning of the second era of global wind power development.

The Californian developments were followed by more sustained market stimulation in Europe which has continued to the present. The European Union (EU) share of the market has been relatively high throughout the whole period of time. Table 1.1 shows that the average European market share over the past 6 years has been more than 70 per cent of the global market. A similar figure is expected for 1997.

Year :	MW World wide	Increase %	European MW	Increase %	Europe share %
1991	240		193		80 %
1992	338	**+41 %**	218	**+ 13 %**	64 %
1993	480	**+42 %**	370	**+ 70 %**	77 %
1994	730	**+52 %**	475	**+ 28 %**	65 %
1995	1290	**+77 %**	836	**+ 76 %**	65 %
1996	1292	**+0.1 %**	967	**+ 16 %**	75 %
1997*	1575	**+18 %**	1265	**+ 24 %**	80 %

- 1997 figures still estimate as per November 1997.

Table 1.1: Installed capacity per year world-wide 1990-96 and the European percentage

1.2 Market creates industry

There are several major milestones in the development of the modern wind industry. California was the training ground for the European wind industry. Some fifty per cent of the generating capacity in California came from European made wind turbines, in particular, Danish 3-bladed stall regulated concept machines. In California it was proven that tax incentives and lucrative utility contracts, together with high wind regimes could create a market boom. For the European wind turbine industry a record high rate of exchange of the US currency made it a genuinely economic wind rush. A more modest, but still lucrative, market in Denmark provided encouragement to new manufacturers in the period 1980-1986. Both markets collapsed in the mid 1980s. In California, the tax incentives disappeared and in addition a weak dollar made the market somewhat bleak. In Denmark an overnight political decision introduced a new requirement that investors must live in the municipality where the wind turbines were located and have a prescribed level of electricity consumption. This political step sent warning signals to bankers financing wind turbine projects. The manufacturers experienced a shrinking credit facility and the market expansion in Denmark came to a dramatic halt.

Markets were re-established in the beginning of the 1990s. The STREG "Stromeinspeise-gesetz" in Germany marked a new era for the wind industry and the manufacturers concentrated on upscaling the wind turbine designs successfully. The NFFO programmes in the UK government set goals in Spain and activity in other European countries gave further stimulation to the industry.

2 CHARACTERISTICS OF THE EUROPEAN INDUSTRY IN GENERAL

In the beginning of the 1980s the average wind turbine size was only about 55 kW and this has increased by more than ten times in just a decade. California and Denmark both have a large number of small wind turbines since they were among the first markets to be developed. Thus, although Denmark and Germany had almost the same number of units installed by the end of 1995, the installed capacity amounted to 1,132 MW in Germany as opposed to 630 MW in Denmark. Table 2.1 illustrates the growth in wind turbine unit rating and the trend towards reduced generating cost since 1980.

Year	**Capacity (kW)**	**Rotor (m)**	**kWh/year** [1]	**Costs ECU/kWh**
1980-1983	55	15	110,000	0.090
1984-1985	75	17	140,000	0.076
1986-1988	120	21	260,000	0.067
1989-1992	250	27	470,000	0.049
1993-1994	400-500	37-40	1,200,000	0.045
1995-1996	500-750	40-48	1,500,000	0.040
1997-	600-1500	43-66	na	na

Table 2.1: Upscaling of commercial machines

The reduction in costs over the years is based on a combination of several factors. The two most significant factors are that the total efficiency has increased (rotor power coefficient (Cp max) has increased from 0.35 to 0.38) while the installed mass per swept m^2 has been reduced. The size increase of wind turbines has also had a positive effect by reducing the costs associated with operation and maintenance (O&M). Today O&M costs are approximately 0.009 ECU/kWh compared to 0.036 ECU/kWh in the mid 1980s. Availability has also been improved significantly from a value of about 60% for the best machines in the 1980s to about 98-99% for a typical commercial wind farm in 1997.

Government R&D programmes for wind power were initiated in the mid 1970s and the test station at Risø in Denmark was founded to establish the standards for wind turbines connected to the public grid. Research stations appeared at ECN Petten in the Netherlands and at Kaiser Wilhelm Koog in Germany. Several other countries launched R & D programmes to investigate wind technology in depth. Market stimulation programmes were introduced in several EU countries. In Denmark the market was stimulated by a subsidy in which 30 per cent of the capital costs of the certified wind turbine was refunded. This was gradually phased out as wind turbines became more and more effective and the programme came to a stop in 1989. In Germany, the introduction of the large scale 250 MW R & D programme and the law *(Stromeinspeisegesetz)* that 90 per cent of the average utility price should be paid for renewable energy generation, made a tremendous step forward in the market. In the UK the NFFO programmes encouraged large wind farm projects. In Spain the P.E.N. - 91 plan aimed for 1,200 MW of connected wind energy supply for the period 1991 - 2000. Direct investment incentives and incentives in the form of support per kWh of electricity produced are among the support mechanisms employed.

Also several other EU countries have set goals in their energy planning where wind energy will play a part in new installed capacity. Overseas, India and the People's Republic of China are setting goals for the exploitation of wind energy.

2.1 Manufacturers

By the early mid 1980s several large companies such as Westinghouse, Boeing, Grumman, MAN and MBB had attempted to enter the wind turbine industry. The aerospace background of these companies impeded them in developing the most appropriate civil technology. More or less all of these industries left the wind turbine business at the time when it was most turbulent and unsure. This left the market place to small and medium sized companies looking for new niche markets related to their established skills. Their origins were the agricultural machinery business, shipyards, electronics industry, mechanical engineering industries. Company development has been substantial since the mid 1980s and the ten largest European wind turbine manufacturers now have very significant sales revenue. In Denmark, for example, the two largest companies, Vestas Wind Systems A/S and NEG Micon, are among the largest 300 companies in terms of sales and these companies alone directly employ some 1,700 people.

Some 8 years ago the only wind turbine manufacturer offering serious competition to the Danish wind industry was US Windpower (later Kenetech). This situation has now changed substantially, and today there are a number of other European manufacturers supplying grid connected wind turbines in the size range of 100-1500 MW. The US industry is represented by Zond Energy Corp. The start up of these manufacturers has been much assisted by national programmes which support the development of wind power utilisation. The nature of the support varies throughout the EU states.

	Accu. MW 1995	Installed MW 1996	Share 1996 %	Accu. MW 1996	Share accu. %
1.VESTAS, DK	996	308	23.8%	1304	20.6%
2.KENETECH, US *	686	20	1.5%	706	11.1%
3.MICON, DK **	397	134	10.4%	531	8.4%
4.ENERCON, D	355	153	11.8%	508	8.0%
5.BONUS, DK	347	117	9.1%	464	7.3%
6.NORDTANK, DK **	344	110	8.5%	454	7.2%
7.TACKE, D *	201	83	6.4%	284	4.5%
8.NEPC, India	226	36	2.8%	262	4.1%
9.MITSUBISHI, Japan	200	4	0.3%	204	3.2%
10.WIND WORLD, DK	154	29	2.2%	183	2.9%
11.NEDWIND, NL	118	32	2.5%	150	2.4%
12.WIND MASTER, NL	121	19	1.5%	140	2.2%
13.NORDEX Balcke-Dürr, DK	97	38	2.9%	135	2.1%
Other manufacturers	937	72	5.6%	1009	16.0%
Total	**5179**	**1155**	**89%**	**6334**	**100%**

* Kenetech is in a mode of declared bankruptcy. Tacke GmbH has been bought by Enron.
** Nordtank Energy Group A/S and Micon A/S merged into the new company NEG Micon A/S on July 4 1997. The combined turnover of these companies will place NEG Micon in 2nd place.

Table 2.2: The largest manufacturers market share (Ranking based on cumulative capacity)

Among some of the newcomers to this list since 1990 are Enercon, Tacke and NEPC. All of these companies have had ideal conditions in their domestic market, but they have little experience outside of their own country. The Danish manufacturers situation is quite the opposite, their main market has been in export.

Among the EU states the Danish participation is the most significant in the world market development. Nearly 50 per cent has been delivered by Danish manufacturers and the equivalent figure in the European market context is 65.6%. In the world market only Kenetech, USA (now in receivership), Mitsubishi Heavy Industries, Japan and NEPC of India have played a significant role in the development of global wind power.

2.2 Size and type of companies

In this section a brief summary of the major wind turbine manufacturers is provided. An exchange rate of 7.4DKK = 2DM = 1 ECU has been used.

Bonus Energy, a Danish manufacturer, has developed and sold wind turbines for more than 15 years. Bonus has sold more than 2000 units. The Bonus wind turbine range extends from 150 kW to 1 MW and their design is based on a 3-bladed, constant speed, stall concept. The new 1 MW machine is a little different from previous models as it employs active stall.

Number of employees	230 people
Annual turnover latest financial year	98 million ECU
World-wide installed MW during 1996	117 MW

Micon A/S, a Danish manufacturer, has developed and sold wind turbines since 1983. Micon has sold more than 2000 wind turbines and manufactures in Denmark, India and the USA. Micon has a license agreement in India with NEPC. Micon´s wind turbine range extends from 225 kW to 1 MW and their design is based on a 3-bladed, constant speed, stall concept. Micon A/S merged with Nordtank Energy Group A/S on July 4, 1997.

Number of employees	249 people
Annual turnover latest financial year	102 million ECU
World-wide installed MW during 1996	162 MW

Nordtank Energy Group A/S, a Danish manufacturer, has produced and sold wind turbines since the early 1980s. More than 2000 Nordtank wind turbines are producing electricity in 15 different countries today. Nordtank´s wind turbine range extends from 550 kW to 1.5 MW and their design is based on a 3-bladed, constant speed concept. Nordtank was floated on the Danish stock exchange in 1995 - the first European wind turbine manufacturer to take such a step. Nordtank Energy Group A/S merged with the Danish Company Micon A/S on July 4, 1997 forming the new company NEG Micon A/S.

Number of employees	225 people
Annual turnover latest financial year	97 million ECU
World-wide installed MW during 1996	110 MW

NEG Micon A/S, a Danish manufacturer formed in late 1997 as a result of a merger between Nordtank Energy Group A/S and Micon A/S. The company is the second largest wind turbine manufacturer in the world. NEG Micon A/S offers WTG´s in the range 150 kW to 1500 kW.

Nordex, a Danish manufacturer, has developed and sold wind turbines since 1987. Nordex was the first to commercialise their 1 MW model especially in Germany. Nordex' wind turbine range extends from 225 kW to 1.2 MW and their design is based on a 3-bladed, integrated gearbox, constant speed, stall concept. Nordex was bought in 1996 by the German company Balcke-Dürr GmbH which is part of the large Deutsche Babcock Group.

Number of employees	130 people
Annual turnover latest financial year	21 million ECU
World-wide installed MW during 1996	31 MW

Vestas Wind System A/S, a Danish manufacturer, is the largest in the world. Since the early 1980s Vestas have installed some 1,200 MW (5500 units) in more than 20 different countries. Vestas manufactures a large proportion of their machines themselves which includes blade production (>12,000 blades have been produced). Vestas' wind turbine range extends from 225 kW to 1.65 MW and all of these are pitch regulated. Vestas uses a partial variable speed system on their 600 kW and 1.65 MW model.

Number of employees	1200 people
Annual turnover latest financial year	257 million ECU
World-wide installed MW during 1996	308 MW

Wind World A/S, a Danish manufacturer, has developed and sold wind turbines since 1987. Wind World has produced more than 900 wind turbines. Wind World's wind turbine range extends from 170 kW to 750 kW and their design is based on a 3-bladed, integrated gearbox, constant speed, stall concept. Wind World introduced a semi variable speed system in 1996. This system is available on the most recent models.

Number of employees	98 people
Annual turnover latest financial year (estimates)	45 million ECU
World-wide installed MW during 1996	40 MW

Enercon GmbH is the largest German wind turbine manufacturer. Enercon was established in 1984 and has worked with energy converters and wind turbine development since then. Enercon introduced a new design concept to the market in 1992/93 which was a multipoled gearless wind turbine. By the end of 1996 some 300 MW of the E-40/500 kW had been installed. They have especially been strong in Germany where they have had a market share of more than 30% between 1994-1996. During 1996 Enercon made a new alliance with the German utility PreussenElektra which is only for export purposes. Enercon has established their own facilities for blade manufacturing.

Number of employees	900 people
Annual turnover latest financial year (estimate by BTM Consult)	144 million ECU
World-wide installed MW during 1996	153 MW

Tacke Windtechnik GmbH is the second largest German wind turbine manufacturer. Tacke started to develop wind turbines in 1984 and grew from a long established gearbox manufacturer. A separate wind turbine company (Tacke Windtechnik) was established in 1990. Tacke manufacture wind turbines in the range 80 kW to 600 kW and installed a prototype of their newest 1.5 MW model in April of 1996. Tacke´s design is a based on a 3-bladed, integrated gearbox, constant speed, stall concept, although their latest 1.5 MW model is pitch regulated and operates at variable speed. Tacke like Enercon has only a little experience outside Germany. Tacke Windtechnik went into receivership in July 1997. Tacke Windtechnik was taken over by Enron Wind Corp in October 1997.

Number of employees	160 people
Annual turnover latest financial year (estimates)	67 million ECU
World-wide installed MW during 1996	83 MW

NedWind Rhenen BV is the largest Dutch wind turbine manufacturer. NedWind was established in 1990 as a merger between 3 different smaller companies who had all been involved in the wind industry since the early 1980s. NedWind is mainly active in the Netherlands but have also installed wind turbines in the USA and India. NedWind´s wind turbine range includes both 2 and 3-bladed WTG´s. They are mainly known by their 2-bladed N40/500kW and N54/1MW.

Number of employees	130 people
Annual turnover latest financial year (estimate by BTM Consult)	30 million ECU
World-wide installed MW during 1996	32 MW

WindMaster Nederland, formerly part of the Belgian HMZ WindMaster company, a very early user of pitch system regulation of the blades, is the second largest wind turbine manufacturer in the Netherlands. WindMaster has been involved in the industry as a manufacturer since 1978 and has installed wind turbines in Belgium, the Netherlands, India, UK and the USA. WindMaster´s wind turbine range also includes both 2 and 3-bladed WTGs. They are mainly active with their 2-bladed 750 kW models today but a 3-bladed 300 kW model is also available from WindMaster. It seems likely that WindMaster will supply WTGs for one of the early offshore developments in the UK.

Number of employees	75 people
Annual turnover latest financial year (estimate by BTM Consult)	17 million ECU
World-wide installed MW during 1996	19 MW

Emerging manufacturers

The following list represents companies who are smaller in terms of production than those listed above, but who nevertheless have significant production.

Desarrollos Eólicos is a Spanish wind turbine manufacturer and 100% owned by Abengoa, a Spanish company engaging in wide ranging activities within the field of power electrics and electronics. Abengoa first initiated a joint venture with the then US Windpower (now Kenetech). This joint venture was ended in 1992. Abengoa then moved on to start a new company called Desarrollos Eólicos. Since then, they have been working on an upgraded 300 kW model based on their AWP 100 turbine and are developing a 600 kW model. Some 60 units of their new 300 kW WTG were installed during 1996. Desarrollos Eólicos has a strong financial partner in Abengoa. Abengoa also owns a company which provides blades for Desarrollos Eolicos WTGs.

Number of employees	102 people
Annual turnover latest financial year	20,4 million ECU
World-wide installed MW during 1996	19,8 MW

Ecotécnia is a Spanish wind turbine manufacturer. They have a 225 kW wind turbine on the market and installed 2 units of their new 600 kW during 1996. This model is expected to be used in several larger projects during 1997. Ecotécnia started working with renewable energy in the late 1970s, primarily solar energy at the beginning. Ecotécnia has like other Spanish companies mainly sold their wind turbines in Spain, with 10 units installed in India in 1995.

Number of employees:	53 people
Annual turnover latest financial year (estimates)	12 million ECU
World-wide installed MW during 1996	18,3 MW

Gamesa Eólica is a Spanish joint venture established and owned by Gamesa Group (51%), Vestas (40%), and Sodena (9%). Sodena is a branch of the local government. Gamesa Group is a large company with activities in most parts of the world. The company is owned by the electricity company Iberdrola (40%), a bank, BBV, (49%), and the founder owns the last 20%. The Gamesa Group has a wide product range including parts for the aviation industry, gear boxes, electronics, composite components etc. The Gamesa Eólica joint venture began at the end of 1993 and is today the largest wind turbine manufacturer in Spain.

Number of employees	250 people
Annual turnover latest financial year (estimate by BTM Consult)	120 million ECU
World-wide installed MW during 1996*	130 MW

* this figure is included in Vestas MW

MADE is 100% owned by the Spanish electricity utility ENDESA. MADE´s largest model on the market is a 330 kW wind turbine, but they are working on a 5-600 kW model of which the first models were installed in 1996. Production is expected during 1997.

Number of employees	(estimated) 80 people

Annual turnover latest financial year (estimates)	17 million ECU
World-wide installed MW during 1996	18,5 MW

It is clear from the descriptions above that only relatively few of the European manufacturers of wind turbines have decided to manufacture their own blades. The rest of the remainder purchase them from specialist manufacturers. A list of the major suppliers follows:

LM Glasfiber A/S, a Danish company, was established in 1940 and is today the largest manufacturer of glass fibre reinforced polyester in Scandinavia. The company has more than 40 years experience with fibre reinforced plastics including some 15 years with advanced carbon fibre construction. Today LM Glasfiber A/S delivers rotor blades for wind turbines to the major part of the wind turbine manufacturers. LM Glasfiber A/S has subsidiaries and/or offices in 6 different countries throughout the world. The company has a turnover of approximately ECU 81 million.

Aerpac bV was established in 1989 as a spin off from Dutch Stork. The company employs some 150 people. Aerpac bV delivers blades for wind turbines in the size range of 200-1500 kW. The company is also active in Spain, the UK and the United States. The company has a turnover of approximately ECU 20 million.

Atout Vent S.A. This French company was launched in 1988. The company`s first blades were for the Darrieus vertical axis wind turbines. Since 1990 the company has built blades for horizontal axis machines in the range from 4 m diameter to 65m diameter. The company employs some 70 people and the turnover is said to be around ECU 5 million.

Rotorline bV This Dutch Company grew from the parent company NedWind bV and is now manufacturing blades for several other manufacturers of wind turbines. Presently the company delivers blades for machines with diameters between 30 and 55m. Lately the company has delivered blades for the 1 MW NedWind wind turbine. Presently the company employs some 60 people and is expected to have a turnover of approximately ECU 5 million.

Abeking & Rasmussen Faserverbundtechnik GmbH This company was established in 1990 as a daughter company of the old shipbuilding company Lemwerder near Bremen. The company employs 130 people and had a turnover of approximately ECU 15 million in the year 1996.

2.3 Export trends

Table 2.3 shows the export share for the largest wind turbine manufacturers during 1996. This year did not show any considerable changes in the export trends among the leading companies. The Danish companies are still exporting a very large proportion of their machines although there was a slight decline in 1996 [2] due to an extremely good year in the domestic market. The German companies are still only exporting a small part of their total sales.

	Total sales 1996 MW	Domestic/MW	Export MW	Export share %
VESTAS	308	80	228	74.0%
ENERCON	153	135	18	11.8%
MICON*	134	74	60	44.8%
BONUS	117	23	94	80.3%
NORDTANK*	110	24	86	78.2%
TACKE	83	74	9	10.8%
NORDEX	38	2	36	94.7%
NEPC	36	36	0	0%
NEDWIND	32	7	25	78.1%
WIND WORLD	29	11	18	62.1%
KENETECH	20	0	20	100%
WIND MASTER	19	14	5	26.3%
MITSUBISHI	4	0	4	100%
Total	**1083**	**480**	**603**	**55.7%**

BTM Consult ApS - November 1997
* Nordtank Energy Group A/S and Micon A/S merged into the new company NEG Micon A/S on July 4 1997.

Table 2.3: Sales to domestic market and export share in 1996

Table 2.3.1 below shows the total sales for the same companies for the past 3 years and the average export share in this period of time.

	Total sales 1994 MW	Total sales 1995 MW	Total sales 1996 MW	Sum 3 years MW	Average Export share
VESTAS	149	273	308	730	79.9%
ENERCON	102	163	153	418	9.3%
MICON*	63	117	134	314	60.8%
BONUS	55	88	117	260	80.4%
NORDTANK*	61	66	110	237	85.7%
TACKE	79	110	83	272	8.5%
NORDEX	22	55	38	115	98.3%
NEPC	62	164	36	262	0%
NEDWIND	23	39	32	94	60.1%
WIND WORLD	24	83	29	136	87.9%
KENETECH	104	150	20	274	52.6%
WIND MASTER	1	23	19	43	49.5%
MITSUBISHI	0.5	2	4	6	66.7%
Total	**746**	**1333**	**1083**	**3161**	**54.0%**

* Nordtank Energy Group A/S and Micon A/S merged into the new company NEG Micon A/S on July 4 1997.
Totally this company's turnover will place NEG Micon in 2^{nd} position.

Table 2.3.1: Average export share for the past 3 years

2.4 Alliances in the market

The companies in the industry are becoming more international. Many of the European companies have established subsidiaries or joint ventures on their export markets. In India more than 20 companies have found local partners. Among these companies are:

Bonus	REPL Engineering Ltd

Micon	NEPC
Nordex	Bharat Heavy Electricals
Nordtank	Textool Company Ltd
Vestas	RBB
Wind World	Arul Mariamman Textiles Ltd
NedWind	Windia Power Ltd
Made	Baron Industries Ltd
Lagerwey	DAS Lagerwey

Several other European manufacturers also took immediate action when the Indian government set the goals in the wind energy exploitation. Some formed their own subsidiary. Enercon established their own subsidiary, Enercon (India) Ltd. LM Glasfiber A/S, the Danish blade supplier, linked up with NEPC.

In 1996 Enercon made a new alliance with the German utility PreussenElektra. This alliance is only for export purposes and has not yet been utilised in any projects.

Vestas established a joint venture in Spain in 1994 with Gamesa Eólica S.A. and with the Italian conglomerate Ansaldo Spa in 1997.

Kenetech of the US established a partnership in the UK (1995) with one of the big utilities in Northern Wales, MANWEB. This alliance has been dissolved as a result of the bankruptcy of Kenetech.

In 1996 the German company Balcke-Dürr GmbH bought 51% of the stocks in Nordex. Balcke-Dürr is part of the large Deutsche Babcock Group which consists of 200 different companies and some 36,000 employees. Balcke-Dürr is mainly active in development of technology for power plants and they had a turnover of about 1 billion ECU in 1995. Enron’s arrival in the wind energy business is thus highly significant.

Zond Systems Inc., (the major US developer) was bought by Enron Corporation in January 1997. Zond will hereby become a subsidiary of Enron Renewable Energy Corp. Enron is involved in the conventional energy business all over the world and also has an interest in solar energy (PV) in the Amoco/Enron Solar partnership. Enron operates the largest natural gas transmission system in America (second in the world) and is also the largest purchaser and marketer of natural gas and non-regulated electricity producer in North America. Enron´s total assets are approximately USD 15 billion [3].

As the American market returns, it is expected that new alliances will be made between US developers and European manufacturers. One alliance has formed outside the USA, between Bonus and SeaWest, directed specifically at the market in Spain (Galicia).

The annual turnover of the wind industry, in the range of USD 1.5 billion, will undoubtedly attract more international companies to the industry. They may come from the utility industry as well as from the financial sector. Alliances between manufacturers and utilities may be a significant future trend.

An interesting development of the past two years is the entry of European Banks into two Danish companies as majority shareholders.

- UBS (Union Bank of Switzerland) became a 75% shareholder of Nordtank Energy Group in December of 1993. Nordtank was floated on the Danish Stock Exchange in the fall of 1995 after which UBS' share was reduced to 14.6%.

- Mees Pierson, previously part of ABN Amro Bank of the Netherlands, bought 70% of the shares in Vestas which since then has increased to some 80% of the total (Dec. 1996).

Mergers

Two major competitors Nordtank Energy Group A/S and Micon A/S have merged to form the new NEG Micon A/S. For historical reasons and in order to provide background information both Nordtank Energy Group A/S and Micon A/S have been listed above as two independent companies.

2.5 Marketing abroad and short term excess capacity

There has been fierce competition in the wind industry over the years. A comparison of world market estimates in Volume 5 (Market Development) with the present manufacturing capacity of the 10 leading manufacturers shows that there may be, in the short term, an excess of manufacturing capacity. Production capacity among present wind turbine manufacturers is approximately 35-40 per cent higher than the present demand. It is estimated that there is a present capacity among manufacturers to cope with a world wide demand of about 2,300 MW without new manufacturing facilities. However, the EWEA’s target for the period beyond 2000 envisages a 3,200 MW production rate. Manufacturing capacity is therefore not a constraint on the wide scale exploitation of wind energy.

It is likely that the market place will remain very competitive. The manufacturers’ capacity is reflected in their marketing and sales efforts and finally in the price structures and their willingness to accept lean orders. The Indian market in 1993-1994 clearly illustrated the highly competitive nature of the business. It is estimated that the five largest wind companies in the world could have supplied almost all the wind turbines installed during 1995 and 1996.
According to Volume 5: Market Development, the annual global market for wind power will not exceed 2,300 MW until beyond the year 2000.

2.6 The role of the European utilities

After early involvement, the major utilities later withdrew from the wind energy market place. The present players have, however, now developed the industry to a level where it is again of interest to the power supply companies.

A major force in the development of wind energy has been the close cooperation between a large group of committed private people as investors, a group of committed manufacturers, and, in some countries, politicians with the political will and vision to create favourable market conditions. To date the role of the utilities has been, at best, passive and, in some cases, actively negative. It is fair to say that the development of the wind energy industry has happened independently of the utilities. This position might change as wind turbines grow to MW scale.

The industry has developed its technology to a point where it is ripe for exploitation by the power companies. The power industry see their customers now dealing with the present wind sector in a context where the share of the global market for energy production is being transferred from fossil fuels to renewables. The most interesting of the emerging renewables, moreover, is wind energy.

It is very difficult to envisage the structure of the electricity industry in 10, or even 5 years, but trends have emerged that suggest the way of the future. Electricity markets are becoming more global. Utilities are looking for development in the international market to expand their activities. Utilities will seek to merge and the number will reduce. The traditional boundaries between utilities such as electric, natural gas and oil are blurring. In order to compete in the impending deregulated energy market many utilities are becoming more diverse energy providers offering electricity and gas and even telephone and other communication services. To the benefit of the wind industry, they will also be providers of green electricity, mainly produced by wind energy, which is presently established as the leading renewable. The pace of these developments will be dictated by the timing and means of implementation of retail market competition. Such competition will occur but a lot of monopolistic road blocks have yet to be removed. It is still not known how comprehensive EU legislation will be.

In order to analyse the likely changes in the electric utility industry, it is necessary to differentiate various elements of the business. The production, the transmission and to a certain extend the distribution will still remain as monopoly businesses. This sector will be controlled by government appointed regulators. Only experience will prove how the legislative world will come to function in the new regime of liberalised energy.

There is a future for renewable energy technologies especially because of the environmental benefits. There is interest in renewable energy in many European countries and in the USA. These benefits have not yet been given a market value, and wind energy has failed to have a widespread appeal among the European utilities because of perceived costs and limitations. There is still a risk that, in a world in transition into a deregulated and competitive utility industry, the utilities interest in renewable energy can diminish. Nevertheless, political and public demands for clean energy can force the utilities to think in new directions. Last, but not least, the continually falling prices per kWh generated by wind power together with growing public interest and political support has given the electricity companies some surprises in their monopoly world.

There are a number of good reasons for an involvement/commitment from the utilities to enter into the world of wind power generation of electricity:

- It is renewable.
- It is pollution free.
- It is cheap - as a supplementary energy source.
- It has grown in size with commercially available wind turbine units large enough to be attractive to the electric utilities.
- It can be installed offshore in large wind parks with fewer planning restrictions
- The main players have become increasingly familiar in utility terms.
- The utilities can buy coal fired plants, nuclear plants, hydro plants and now also wind plants from the same company. The portfolio has been extended with the addition of the wind farm package.

In addition to the continuously improving technology, continuously decreasing prices, there has been a significant shift in the structure of the industry which has made the industry, as well as the machine, more “utility friendly”.

2.7 The internal and deregulated market

Wind energy in a liberalised European electricity market

In December 1996, the Council of Ministers of the European Union decided to launch a Directive on Liberalisation of the electricity market in Europe. The purpose behind this action is to include trading of electricity into the free market, as already done for almost all other goods and services. The reason for the late opening of the electricity market has been in the complexity of the utility industry, which in most countries has been a national monopoly or in other ways a protected sector without competition. The directive has been under negotiation for eight years, indicating how politically sensitive a subject it is! The directive will be in force by January 1st 1999 and before that all member states must include legislation and regulation on a national level to fulfil their contribution to the opening of the market.

The main contents of the new directive, which is a limited opening of the market over a period of 5 years, are listed below:

- Each country shall open its market to the extent of about 22 % from January 1999 and, the preparation will be increased to 32 % by January 2003.
- The liberalisation is created by the so-called TPA (Third Party Access), to be effected after two models: Negotiated Access/Regulated Access or by the Single Buyer Model (National System Operator take care of all trade on behalf of national consumers).
- Consumers who take more than 100 GWh (one hundred million kWh) per year, will always be allowed to buy their electricity where they want within the Union.
- Utilities will be reorganised in a way which separates production, transmission and distribution and the individual cost elements will be made transparent to the consumers.

- Monopoly status will only be available for System Operators and they will be under a strong control by the government to secure equal and non-restrictive access to the grid for all "free consumers" and electricity generators (providers).
- The member states are allowed to include extra costs for environmental requirements, and for other national strategic requirements related to their energy sector, e.g. security of supply. This allowance, which is not governed by the free market competition, is called PSO (Public Service Obligations). PSO costs will be distributed equally to all consumers within the country, and also among those buying cheap electricity from a foreign supplier.

The main intentions behind the Directive are:

- To increase the efficiency of electricity production and distribution.
- To make the cost of electricity production and distribution transparent to the customers.
- To stimulate cross-border trade and alliances within the utility industry.
- To save "surplus capacity" costs by more efficient use of existing power capacity.
- To maintain "security of supply" and secure low electricity prices for European consumers taking into account environmental issues related to electricity production.

The new Directive is being discussed in the electricity sector all over Europe. Many utilities have already taken strategic decisions about how to prepare themselves for the competition and to secure their future business. Alliances between producers in many countries and agreements on back-up capacity, etc. are under negotiation.

The big questions for the wind industry and other renewable technologies are : “Will renewable technologies be able to survive in that market? How will the prices move? Will priority be given to renewable generators?”

The answers are not simple. Experience from a few markets, which have established some kind of liberalisation is sparse. The UK, Norway, Sweden and Finland have started deregulation and/or privatisation of their utility sector.

No simple conclusion is evident as to whether deregulation favours or disadvantages the development of wind energy. The UK is a special case in this context - they have developed wind energy projects in the period when deregulation has taken place. This expansion in the UK is a result of the way in which the details of privatisation were organised and not as a result of privatisation per se.

Several studies have been carried out assessing the impact of the future liberalised electricity market on new renewable technologies. Some studies conclude that there will be hard times for renewable energy due to the fact that established utilities will be able to offer electricity at "short-term" marginal prices. Others rely on the use of the PSO tool, to provide security for a continued development and on national priority to support demand for renewable electricity.

The crucial point is: Will PSO costs - defined by national authorities and government - be accepted by the Commission and the EU Court if they contravene "free competition" requirement? There will be broad areas in which it can be a matter of interpretation of the directive whether a specific cost is a PSO element or a trade barrier.

The following advantages accrue for wind power in a liberalised market :

- Access to renewable generators will be easier.
- If the local supplier refuses to buy the electricity from a wind turbine there may be other customers elsewhere in the Union.
- Transparency of cost for thermal and nuclear generation will be to the benefit of wind energy, because wind energy does not have the "hidden costs" associated with conventional generators.
- Groups of consumers which have a preference for electricity from renewable energy sources, will be able to pool their purchase and find renewable generators to provide their electricity.
- Future offshore plants in the northern Europe may benefit from the expected strengthening of transmission lines from north to mid and south of the European continent.

There are also threats to wind energy in a liberalised market:

- Established and economically consolidated utility companies can offer very low prices to gain market shares, based on marginal cost calculations.
- Discussion between national parliaments and the EU Commission about justification of certain regulations for wind power (priority or prices) may create sustained periods during which the business is "stalled", awaiting notification of new laws and regulations.

The wind industry must examine the liberalised market treating it as a challenge which offers new opportunities for the sale of electricity. It must then fight hard to maintain the legitimate rights of renewable energy in the European electricity systems.
This argument is likely to be sustained on the basis of advantages to the environment and in "use of local resources".
If the European Union decides on specific targets for individual countries for reduction of CO_2 emission and makes such quotas tradable, then the liberalised market might be an excellent tool for rapid development of a “CO_2 free market” for electricity within the traditional market - a market with its own price level.

The framework for such a trade of CO_2 reduction must however be considered carefully, in order to ensure that countries do not simply trade CO_2 and avoid making any real efforts at CO_2 reduction in their own territory. There is a benefit to the EU in that such trade would allow better exploitation of the resources in a country blessed with good wind: the wind generated electricity could be exported to another country which has poor resources.

3 EMPLOYMENT AS OF 1996-97

A small survey conducted by BTM Consult ApS on the employment figures among the European manufacturers during the summer 1997 produced the following figures for the direct employment in the wind industry.

Manufacturer	No. of employees
Vestas	1200
Enercon	800
Gamesa	250
Micon	249
Bonus	230
Nordtank	225
Tacke	160
Nordex	130
NedWind	105
Wind World	98
Other European	600
Direct employment	**4047**

Table 3.1: Present employment status at selected wind turbine manufacturers [4]

The European manufacturers delivered some 1000 MW capacity in the year 1996. It should be stressed that the majority of the European wind turbine manufacturers are assemblers of components made by firms in other parts of in Europe. There is, therefore, a long list of associated sub-contracted suppliers providing components to the industry.

4 FUTURE EMPLOYMENT IN A EUROPEAN CONTEXT

Two extensive studies [5] have been undertaken recently on the subject of employment creation in the wind energy sector. A summary of the findings of these two studies is provided in the following paragraph:
In 1995 wind power created some 9,000 jobs in Denmark, including jobs with Danish turbine component suppliers. The impact on global employment from the manufacturing process is some 12,000 jobs. The installation of Danish turbines world-wide created another 4,000 jobs. Danish wind turbine manufacturers supply approximately half of the nameplate generating capacity in the world market. One may therefore estimate world-wide employment in the wind power industry to be in the range of 30,000 to 35,000 jobs in 1995.

However, the calculation of indirect employment is difficult in any industry and wind energy is no exception. Both investigations have shown enough evidence for the following statement to be used in a calculation for present and future employment in the wind energy sector in Europe.

1 MW of wind power installed creates jobs for 15-19 people under present European market conditions. In more labour intensive parts of the world this figure may double.

4.1 Potential future employment in the EU

In this section the figures above are used to estimate how many jobs may be expected within the EU member states. Table 4.1 has been used in Volume 5: Market development, and is now repeated to show how many jobs can be expected in the EWEA scenario.

Year	**EWEA goal** MW of installed Wind Power Capacity by end of the year	**Jobs created by the wind energy installed capacity** Man Years
1996	3.500	
2000	8,000	72,000
2010	40,000	512,000
2020	100,000	960,000

Table 4.1: Jobs created by the wind industry

It is noteworthy that should there be an installed capacity of 100,000 wind capacity there will be considerable maintenance, service and repairs to be undertaken during the operational life. There will also be refurbishment of the installed capacity.

It is estimated that the design life time of a wind turbine is approximately 20 years. From year 2030 and onwards the rate of refurbishment will be 5 per cent of the installed capacity equal to 10,000 MW capacity.

4.2 Offshore

Offshore installations will present a very large new potential for the development of wind energy. Within the EU states there have been offshore installations in Sweden, the Netherlands and Denmark which are listed below:

Location	**Units**	**Made/Size**	**Capacity MW**	**Year**	**Country**
Nogersund	1	Wind World 220 kW	0.22	1990	Sweden
Vindeby	11	Bonus 450 kW	4.95	1991	Denmark
Lely (Ijsselmeer)	4	NedWind 40-500 kW	2.0	1994	Netherlands
Tunø	10	Vestas V39-500 kW	5.0	1995	Denmark
Dronten I (Ijsselmeer)	19	Nordtank 600 kW	11.4	1996	Netherlands
Total units	**45**	**Total capacity MW**	**23.57**		

Table 4.2: Installed offshore projects in the world

The first offshore wind turbine was installed in 1990 by Wind World in Sweden. Since then four other projects have been installed, two in Denmark and the other two in the Netherlands. Table 4.2. shows that all together there are 45 wind turbines with a total capacity of 23.57 MW. A new offshore wind farm was installed in the Netherlands by Nordtank. This offshore wind farm consists of 19 units and is the largest so far.

All of these offshore projects are installed relatively close to the shoreline, between 1-5 km. The most recent project which is at Dronten in the Netherlands is located just some few metres off a pier. These projects are all intended as pilot or pre-commercial projects. Many aspects of offshore operations must be explored before large scale development can start, such as technical durability under these conditions, access for service, their impact on birds, fish, etc.

Large scale offshore wind power development will therefore most likely not begin before the end of this century, when the large scale 1.65 MW wind turbines have been well tested on land. A potential of 8,000 MW has already been identified on just 4 different sites in the surrounding waters of Denmark. These areas are all located within 20 km offshore and with shallow water between 5-10 metres. The Danish government estimates that some 4,000 MW of offshore wind power will be installed by the year 2030. The Danish Minister of Environment & Energy announced in March 1996 that a new committee with members from the Danish Energy Agency and the Danish utilities should have a plan prepared for future offshore wind energy development by the 1st July 1997. There are also major plans for offshore wind energy in Sweden, Germany and the Netherlands. A contract has already been let for a 30 MW wind farm under the UK NFFO.

It is likely that the offshore market will demand large scale machines which are already available in prototype form for application onshore. For the most part, manufacturers seem to adhere conceptually to the design principles of their smaller machines in the design of their MW plant.
According to information provided by manufacturers, MW machines will be delivered to projects in 1997 in increasing numbers. It is expected that as the offshore market evolves new machines will emerge which are optimised for that particular application.

Both development in the offshore market and in the MW class of wind turbines will require many new skills from the handling of raw material in the factory to the management of system for access and erection. The development of MW technology for offshore will push transportation and logistical factors to the limit. Much of this way has already been paved by the offshore oil industry but specific issues of power system electrics within wind farms and many others will require attention.

The exercise to locate suitable sites for the installation of offshore wind power requires skill in some new areas:

- archaeology
- biology
- geology

- marine-biology

There will be further requirements to deal with commercial fisheries, defence and communications agencies.

An investigation by a consortium in the Danish utility area showed foundations to be significantly cheaper than was previously anticipated. This implies that deeper water locations can be more readily exploited. One of the major challenges offshore lies in the logistics of maintenance and repair, daily monitoring and control of offshore installations. The present experience is very limited. As can been seen from the Table 4.2, only a few projects have more than three years of continuous operation. Experience gained so far does not show any significant increase in maintenance costs, although problems with access have been experienced.

There is, however, a strong belief that, in the long run, costs may decrease further due to an environment with much less turbulent air flow through the rotor. It is nevertheless a challenge to the manufacturers to present evidence that some of the basic specifications of an offshore wind turbine are fulfilled.

- relatively airtight nacelle
- system for dehumidification
- finish of all surfaces according to highest corrosion class
- heat exchanger for cooling air for generators as well as gearboxes
- permanent crane or lifting equipment in nacelle for small component changes with fixing points for the cranes
- transformer and high voltage switch gear inside tower

These are a few new areas requiring attention to allow the considerable promise of offshore wind power to be realised. Above all it will be a new challenge to the industry to provide this market with effective access and low maintenance costs.

As a result of this new market, new and powerful progress will emerge. Many offshore engineering and oil companies are already showing considerable interest in this new area of business. The entry of such companies into the wind energy industry will add further credibility.

5 WIND ENERGY BECOMES “BIG BUSINESS”

The development of the wind energy sector as indicated by the forecasts presented in Table 5.1 may catch the attention of large companies in the power industry. This table shows the development in the wind energy sector in terms of MW installed. There may be a transitional period with other company takeovers and mergers, but in the long run there is undoubtedly enough turnover and employment in the wind industry to create the necessary interest for the big power supply companies. The pioneering stage is over. The wind industry is entering a transitional phase and within the next decade will be recognised as a conventional form of electricity generation.

Energy conglomerates, such as Royal Dutch Shell, British Petroleum, Amoco, Exxon and Statoil, and industrial combines, for example General Electric, Westinghouse ABB, Siemens, Mitsubishi, Nissho Iwai, Howden Power, and Neste OY are all expressing an interest and are likely to enter into this market in one way or another.

Wind energy is now joining the realms of ‘big business’ and needs to achieve a better understanding of the structure of the energy industry in order to match its high level of technical innovation with commensurate financial profits.

Country (area)	Installed capacity (MW) by end of 1996	Installed capacity during year						Installed capacity between 1997-2001	
		1996	**1997**	**1998**	**1999**	**2000**	**2001**	**Sum**	**Accu.**
USA	1.596	12	50	150	150	200	400	950	2.546
Canada	21	0	10	30	50	100	100	290	311
Latin America	34	22	30	50	50	100	120	350	384
Total America	**1.651**	**34**	**90**	**230**	**250**	**400**	**620**	**1.590**	**3.241**
Denmark	835	200	300	125	125	150	150	850	1.685
Finland	7	1	5	10	10	10	20	55	62
Germany	1.552	420	450	300	300	300	300	1.650	3.202
Greece	29	1	40	50	50	50	50	240	269
Italy	71	38	40	40	40	40	50	210	281
Rep. Ireland	11	4	40	30	30	30	50	180	191
Netherlands	299	50	50	50	50	50	100	300	599
Portugal	19	11	10	10	10	10	20	60	79
Spain	249	116	200	250	250	250	250	1.200	1.449
Sweden	103	34	20	50	50	100	100	320	423
UK	273	73	60	100	150	100	100	510	783
Other European countries	49	20	50	100	125	125	200	600	649
Total Europe	**3.496**	**967**	**1.265**	**1.115**	**1.190**	**1.215**	**1.390**	**6.175**	**9.671**
P.R. China	79	35	100	150	150	150	200	750	829
India	820	244	50	300	500	500	500	1.850	2.670
Other Asian countries	13	3	10	50	50	50	75	235	248
Total Asia	**912**	**282**	**160**	**500**	**700**	**700**	**775**	**2.835**	**3.747**
Australia & New Zealand	6	4	5	20	20	20	30	95	101
North Africa	9	0	10	100	75	75	75	335	344
Middle East	10	2	15	20	30	30	30	125	135
Former Soviet Union: FSU-countries	18	1	10	10	20	20	50	110	128
Rest of the world	3	3	20	20	20	20	20	100	103
Total other continents and areas:	**46**	**9**	**60**	**170**	**165**	**165**	**205**	**765**	**811**
Total MW new capacity every year:		**1.292**	**1.575**	**2.015**	**2.305**	**2.480**	**2.990**	**11.365**	**17.469**
Accu. capacity (MW)	**6.104**	**6.104**	**7.679**	**9.694**	**11.999**	**14.479**	**17.469**		

Table 5.1: Forecast for wind power development 1997-2001

Country (area):		Installed wind power capacity by the end of 1996 and 2000. Expectations for new capacity between 2000-2005. All numbers are MW/year						
Accumulated installed capacity (MW) by 1996		**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**Accu. 2001-2005**
North America	1617	2567	400	500	500	700	700	2800
S & C. America	32	382	120	120	200	250	300	990
Total America:	**1649**	**2949**	**520**	**620**	**700**	**950**	**1000**	**3790**
Denmark	835	1210	150	150	150	150	150	750
Germany	1552	2302	250	300	300	400	500	1750
Netherlands	309	509	150	200	200	250	250	1050
Spain	249	799	200	200	200	300	300	1200
Sweden	103	243	100	100	150	250	300	900
UK	273	723	150	250	250	300	300	1250
Other EU-countries	133	593	150	150	200	200	300	1000
C. Europe + Russia	67	507	100	100	150	150	200	700
Total Europe:	**3520**	**6885**	**1250**	**1450**	**1600**	**2000**	**2300**	**8600**
India	820	2720	500	500	500	500	500	2500
P. R. China	67	617	200	300	400	500	500	1900
Other Asian	13	173	75	100	150	150	200	675
Total Asia	**900**	**3510**	**775**	**900**	**1050**	**1150**	**1200**	**5075**
Australia and New Zealand	6	76	30	30	50	100	100	310
M. East & Africa	18	258	100	100	150	200	250	800
Rest of the world	5	25	10	10	15	15	15	65
Total others	**41**	**386**	**140**	**140**	**215**	**315**	**365**	**1175**
World per year			2685	3110	3565	4415	4865	18640
Annual growth rate				15.8%	14.6%	23.8%	10.2%	
Accu. Installed MW	**6110**	**13715**	**16410**	**19520**	**23085**	**27500**	**32365**	
Accu. Growth rate			19.6%	19%	18.3%	19.2%	17.7%	

Source: 1995-2000, BTM-C forecast from 1995, (adjusted by June 1996). 2001-2005, BTM-C, December 1996
The annual growth in MW of 2 - 5.000 equal to a value of approximately 1.4-3.5 billion ECU per year over the coming years will be interesting for the energy supply society.

Table 5.2: Expectations for global wind power development until the year 2005

6 CONCLUSIONS

The wind industry is still developing at a rapid pace. It is moving from a pioneering stage in both technological and commercial terms. As the technology matures, the cost reduces and the market expands, the industry is being recognised as an exciting and vibrant entity, and major players who have hitherto been reticent about identifying themselves with renewable energy, are now keen to join in. This move is to be welcomed and is a clear sign that in commercial terms wind is just one of the alternatives along with coal, oil and gas - part of the energy industry. Given appropriate market conditions the wind energy industry will provide tens of thousands of jobs in an exciting clean industry.

7 REFERENCES AND NOTES

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1 The production is based on an average yearly wind speed of 6 m/s (Rayleigh). Costs are based on a 20 years lifetime and 7% interest.

2 There was a small increase of MW exported, but the domestic market doubled which resulted in a decline of the export percentage.

3 Official News Release from Enron of January 6, 1997 and information from the Internet.

4 Some companies among the investigated have refrained from participating in this survey

5 Danish Wind Turbine Manufacturers Association and Danish Counties and Municipalities Research Institute (Society Value of Wind Power).

European Commission
Directorate-General for Energy

WIND ENERGY - THE FACTS

Volume 4

THE ENVIRONMENT

EXECUTIVE SUMMARY

"Coal, gas and oil will not be the three kings of the energy world for ever.
It is no longer folly to look up to the sun and wind, down into the sea's waves" [1]

Benefits of wind energy

Wind energy has a number of important environment benefits. It is a new means of clean, renewable and sustainable electricity generation.

It is also one of the most cost-effective renewable energy options for reducing global warming, resulting in less than 1% of conventional generation CO_2 emissions per unit of electricity delivered.

The plant operating today already avoids over 6,300,000 tons of CO_2, 21,000 tons of SO_2 and 17,500 tons of NO_x emissions per year in the EU alone.

Future capacity will avoid over 28,000,000 tons of CO_2, 94,000 tons of SO_2 and 78,000 tons of NO_x emissions per year outside the EU by 2005. Wind power has the potential to reduce EU power sector CO_2 emissions by over 11% by 2040.

There are other advantages that are relevant to issues rising up the political agenda. Unlike other forms of electricity generation, wind farms do not create any dangerous waste products.

The continuity of fuel supplies is a strategic and economic consideration, wind energy is indigenous, secure and freely available. The preservation of fossil fuel reserves will, in the long term, mean they can be used more efficiently. Wind preserves precious fossil fuels for essential uses in sectors such as transport and petrochemicals.

Effects of wind energy

All power generation has environmental effects, those wind produces are minimal.

About 99% of the land area within a typical wind farm site is available for agricultural or other use. 1,000 modern wind turbines in a 10 x 10 km array could provide 10% of the electricity for a country such as Denmark.

Independent surveys of people living near or visiting wind farms show the majority like them.

Wind turbine and wind farm designers carefully minimise effects such as sound, visibility, shadow flicker and electromagnetic interference.

Production of generating plant uses energy. In 3 to 4 months a modern wind turbine on an average site will generate as much energy as that used to manufacture it.

The cost and logisitics of shutting down nuclear or fossil fuel powered stations can be immense and complicated. Wind farms can be decommissioned, and sites fully restored, very easily.

The recyclable content of wind turbines is increasing and more energy can be recovered from, than is used in, scrapping machines.

Planning

Wind farm development is strictly controlled by stringent planning requirements throughout the EU. "Best practice" is widely adopted by the industry as only responsible development can ensure long term success.

Conclusion

Wind energy does not, defer the environmental costs of electricity production to future generations.

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1 INTRODUCTION

Wind energy has many positive environmental facets. Indeed, one of the principal market drivers for wind energy is the fact that it is a clean, renewable and sustainable means of generation. This is especially important in regions such as the European Union (EU) where, in general, adequate installed capacity to meet foreseeable demand already exists. This document provides an objective summary of current understanding of the environmental issues involved in wind energy. Where available, information from authoritative independent sources and various studies funded by the European Commission has been used. Inevitably, however, this has had to be supplemented by the specialist knowledge of experts within the wind industry. It is not a primary objective of this document to criticise other generation technologies, but some quantification and description of their impacts has been necessary to assess the environmental benefits of wind energy.

1.1 Renewables and Energy Conservation

Renewables and energy conservation are complementary rather than competing approaches to the same challenge of sustaining acceptable standards of living and economic performance with greatly reduced environmental impacts. World annual energy demand is predicted by the International Energy Agency to double from the current level of 400 EJ to 800 EJ in 2030 as the developing countries industrialise. It is estimated that 60% of incremental generation in China, India and the former Soviet Union will be coal-fired. Whatever the primary source of energy, it clearly makes both economic and environmental sense to use that energy as efficiently as possible. Decoupling economic performance from energy consumption remains a long term imperative.

1.2 Wind Energy in a Portfolio of Environmental Measures

Wind energy does not purport to be the panacea for a sustainable global energy future. However, independent studies in several EU Member States suggest that wind energy could provide about 20% of electricity generated within the existing transmission and distribution structures, and that the associated capacity value up to these levels is roughly equal to the capacity factor, typically 20-40%. More generally, renewables already provide about 5.3% of primary energy in the EU, the largest contribution being from large hydro schemes. The declared target of the European Commission’s Altener programme is for this level to increase to 8% by 2005, while the corresponding target in the Commission’s White Paper is 12% by 2010.

1.3 Amenity and Ecology

The discussion of the localised environmental effects of wind energy in this volume will differentiate effects on amenity from those on ecology. "Amenity" in this context includes factors affecting human perception or behaviour. Important among such factors are visual and landscape issues, sound and electromagnetic interference (EMI). Although none of these effects on amenity outlasts the operational life of the development, they are generally at least as significant as effects on ecology in shaping public opinion and determining whether or not a proposed development will receive planning permission.

"Ecology" in this context embraces all direct and indirect material effects upon flora and fauna. Common concerns include birds, rare vegetation types and changes to local hydrology. Regional, national and international land designations indicate where unacceptable effects may be anticipated and often form an integral part of planning guidance.

2 ENVIRONMENTAL BENEFITS

2.1 Avoided Emissions

Every unit (kWh) of electricity produced by wind turbines displaces a unit of electricity which would otherwise have been produced by a power station burning fossil fuel. It is easy to calculate the rate of emissions during the production of electricity from individual coal fired, oil fired and gas fired power stations. However, such rates will vary across the EU with factors such as plant efficiency, abatement measures, operating regime and fuel composition, as illustrated by the estimates of grams emitted per unit of electricity output for fossil-fuelled generating plant in three Member States shown below.

Pollutant	Netherlands (g/kWh)	UK [2] (g/kWh)	Denmark (g/kWh)
CO_2	872	936 - 1079	850
SO_2	0.38	14.0 - 16.4	2.9
NO_x	0.89	2.5 - 5.3	2.6
Slag and ashes	N/A	N/A	55
Dust	N/A	N/A	0.1

Table 1: Specific emissions from fossil-fuelled generating plant in three Member States

Specific emissions from conventional power sources are, in general, decreasing due to increases in efficiency and the use of pollution abatement equipment. The consequences of, and counter-measures available to deal with, each type of emission will now be discussed in greater detail.

2.1.1 Avoided emissions of global warming agents

The concentration of atmospheric CO_2 has increased by 25% since pre-industrial times, and it is expected to double by around 2050. The Intergovernmental Panel on Climate Change (IPCC) estimated in 1996 that the global average temperature has increased by 0.3-0.6 ºC since 1900, and projects a further rise relative to 1990 of 1.0-3.5 ºC (with a best estimate of 2.0 ºC) by 2100. Mean sea level is expected to rise by 15-95 cm. Global warming due to anthropogenic emissions is now generally accepted as fact, and IPCC scientists expect major ecological changes to occur.

In March 1997 the European Commission undertook to reduce total EU emissions of greenhouse gases by 15% by the year 2010. This agreement between the EU Member States was conditional upon a similar agreement being reached at the UN Conference in Kyoto (Japan) in December 1997. Figure 1 overleaf shows the targets for each of the 15 Member States within this CO_2 reduction goal.

In the EU, approximately one third of CO_2 emissions come from power generation. For every 1% of conventional generation capacity displaced by renewables, a 0.3% reduction of total CO_2 emissions is achieved.

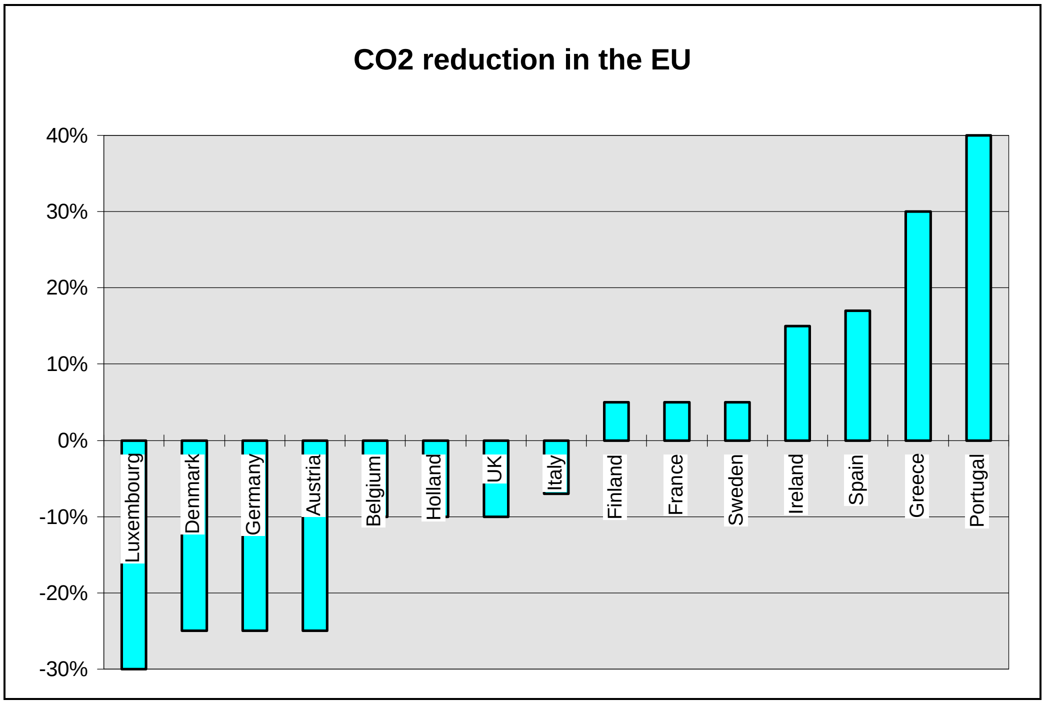

Figure 1: Target CO_2 emissions in 2010 compared with present levels, by Member State

Wind energy offers one of the cheapest renewable energy options for reducing CO_2 emissions from electricity generation, as shown by Figure 2 below.

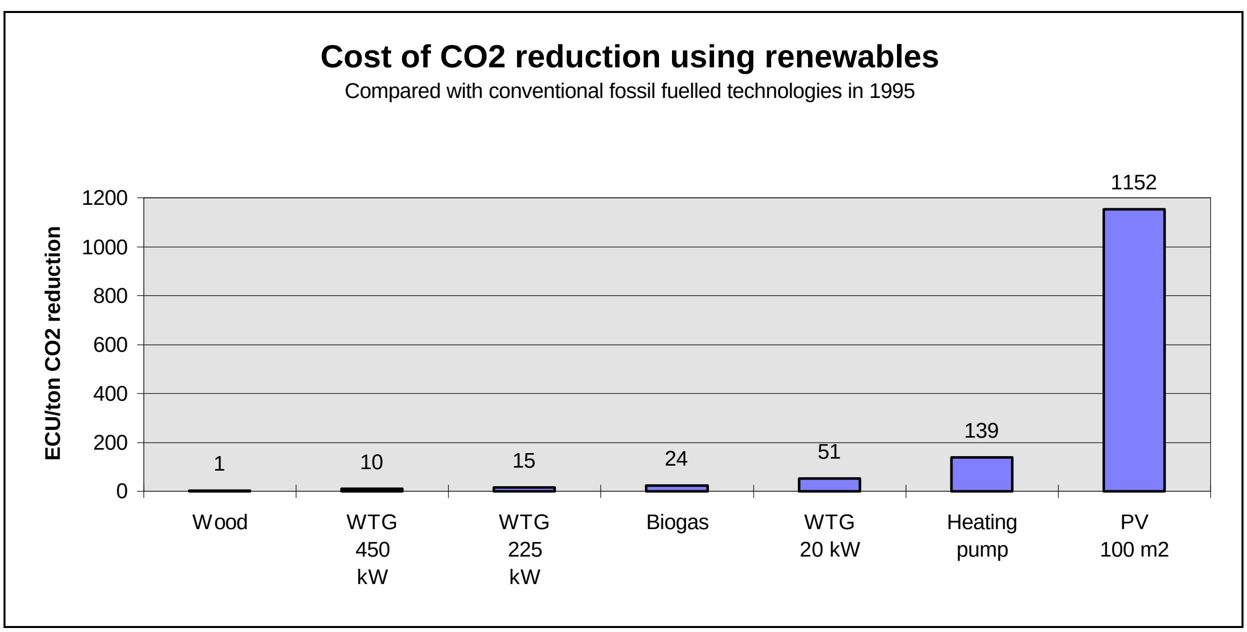

Figure 2: Cost per ton of avoided CO_2 emissions for different technologies [3]

A modern 600 kW wind turbine in an average location will, depending on the site wind regime and hence the capacity factor, prevent the emission of some 20,000 - 36,000 tonnes of CO_2 from conventional sources during its 20 year design life.

Table 2 [4], published in the World Energy Council's 1993 report "Renewable energy resources: opportunities and constraints 1990-2020", compares emissions from different electricity generation technologies.

	CO_2 Emissions (Tonnes per GWh)			
Technology	**Fuel Extraction**	**Construction**	**Operation**	**Total**
Coal-fired [5]	1	1	962	964
AFBC	1	1	961	963
IGCC	1	1	748	751
Oil-fired	-	-	726	726
Gas-fired	-	-	484	484
OTEC	N/A	4	300	304
Geothermal	<1	1	56	57
Small hydro	N/A	10	N/A	10
Nuclear [6]	~2	1	5	8
Wind	N/A	7	N/A	7
Photovoltaics	N/A	5	N/A	5
Large hydro	N/A	4	N/A	4
Solar thermal	N/A	3	N/A	3
Wood [7]	-1509	3	1346	-160

Table 2: CO_2 emissions from different electricity generation technologies

Of the four technologies listed above with lower specific CO_2 emissions than wind energy, only large hydro is currently commercially competitive. However, it has been argued in both Canada and Brazil (two countries where further large hydro schemes are planned) that rotting vegetation in dam reservoirs gives off substantial amounts of greenhouse gases [8]. Principal among these is methane which is some 50 times as potent a global warming agent than CO_2. Large hydro schemes are also being abandoned because of their destructive effects on wildlife, habitats and public protest.

No satisfactory or commercially viable means of abating CO_2 emissions from fossil-fuelled plant has yet been devised. The specific emissions of gas-fired plant are approximately half those of coal-fired plant, and the low capital cost of CCGT stations has led to a massive deployment of this technology in recent years. However, it could be argued that it makes little sense to squander a prime fuel on electricity generation at a current maximum of 57% efficiency when it can be used directly for heating at over 90% efficiency.

2.1.2 Avoided emissions of acidification agents

The major quantified effects of acid deposition are upon human health, building materials and commercial forestry, with a smaller effect upon crops. In addition, there are major impacts upon ecosystems, both terrestrial and aquatic, notably in the lakes of Scandinavia. Damage costs derived using previous estimates of acidification equate to approximate values of 6000 ECU per tonne for both SO_2 and NO_x.

Impacts are non-localised in that they may be experienced hundreds, if not thousands, of kilometres from the point of emission. They are not, unlike anthropogenic greenhouse gas emissions, truly global.

Table 3 compares emissions of SO_2 and NO_x from fossil-fuelled generating plant with those from wind turbines. This data was produced by combining the data presented in Table 1 with ExternE estimates for the wind energy life cycle, and is a conservative comparison as the figures for the fossil plant were not calculated on the same life cycle basis but from monitored outputs during the generation process only. Nonetheless, it can be seen that the specific emissions of SO_2 and NO_x from wind turbines are respectively only 0.53-22.9% and 0.68-4.04% of those from fossil-fuelled plant. The large discrepancy between national emission rates is due to a combination of different fuel sources and the more widespread use of flue gas desulphurisation (FGD) equipment in Denmark and the Netherlands.

Pollutant	Fossil-fuelled Plant			Wind
	Netherlands (g/kWh)	UK (g/kWh)	Denmark (g/kWh)	Turbines (g/kWh)
SO_2	0.38	14.0 - 16.4	2.9	0.087
No_x	0.89	2.5 - 5.3	2.6	0.036

Table 3: Specific emissions from fossil-fuelled generating plant and wind turbines

FGD increases significantly the capital and running costs of fossil-fuelled plant and thereby the unit costs of electricity generated. The process requires the quarrying of large quantities of limestone which is often located in scenic areas. The waste product is gypsum which, although usable in construction materials such as plasterboard, would be produced in quantities far in excess of foreseeable requirements if FGD was universally implemented and would, therefore, constitute a secondary waste disposal problem.

2.1.3 The benefits of wind energy

Table 4 below summarises some of the avoided emissions attributable to wind energy deployed in the EU as of December 1997:

Parameter	Quantity
Installed capacity	4,425 MW
Energy produced	8,8 TWh/yr
Avoided CO_2 emissions	7,800,000 tons/yr
Avoided SO_2 emissions	26,000 tons/yr
Avoided NO_x emissions	22,000 tons/yr

Table 4: Annual avoided emissions achieved by existing wind energy in the EU

Estimates of global onshore availability, assuming 0.33 MW/km^2 average for land with >5 m/s annual mean wind speeds, indicate that the maximum technical wind energy potential is about double current global electricity production [9]. Exploration of the offshore potential for wind energy is only just beginning. Closer to home, one of the targets of the Altener programme is to increase EU electricity production from new renewable energy sources from 25 TWh in 1991 to 80 TWh in 2005. Within this target, the goal for wind energy is 8,000 MW of installed capacity which could produce 16 TWh of electricity per year. This would bring a saving of over 14 million tonnes of carbon dioxide per year. Table 5 estimates the avoided emissions in the EU which could be achieved if wind energy was developed in line with the latest EWEA goals. In generating these estimates it has been assumed that specific emissions (Tonnes/TWh) from fossil plant displaced by the wind turbines are reduced across the board by 10% of year 2000 levels each decade thereafter over the period covered. Such assumptions may well be optimistic, in which case the avoided emissions would be even higher.

Year	EWEA Goals for MW installed wind power capacity	Production TWh/year	CO_2 reduction Tonnes/year	SO_2 reduction Tonnes/year	NO_x reduction Tonnes/year
2000	8,000	16	14,400,000	48,000	40,000
2005	20,000	40	34,200,000	114,000	95,000
2010	40,000	80	64,800,000	216,000	180,000
2020	100,000	200	134,400,000	480,000	400,000

Table 5: Annual avoided emissions achievable by projected wind energy in the EU

The CO_2 emission from power generation in the EU was 973 million tonnes in 1992. According to a conventional wisdom scenario [10] this number is expected to increase to 1,195 million tonnes CO_2 per year, in the year 2020. If the EWEA´s goal for wind power development was met by the year 2020, it would be possible to reduce the EU's power sector CO_2 emissions by over 11% using the assumptions described above.

It is estimated that around 16,500 MW of wind power will be installed in non-European countries between 1997-2005 according to prognosis for global wind power development. The environmental benefits in these countries will often be larger since wind power will replace electricity which would otherwise have been produced by highly polluting fossil fuelled power plants. Even using the same assumptions as in Table 5, these avoided emissions would be over 28,000,000 tonnes/year of CO_2, 94,000 tonnes/year of SO_2 and 78,000 tonnes/year of NO_x.

2.1.4 Other avoided emissions from fossil fuels

Other annual emissions from a typical 2000 MW fossil-fuel power station have been estimated as follows:

Pollutant	Conventional	Conventional	Combined-cycle

	Coal (tonnes per year)	Oil (tonnes per year)	Gas (tonnes per year)
Airborne particulates	7000	3000	negligible
Carbon monoxide	2500	3600	270
Hydrocarbons	750	260	180
Hydrochloric acid	5000-20000	negligible	negligible
Solid waste and ash	840000	negligible	negligible
Ionising radiation (Bq)	10^{11}	10^{9}	10^{12}
Trace elements	Depends on source		

Table 6: Emissions from typical 2000 MW fossil-fuel power stations [11]

Carbon monoxide blocks oxygen transport in the blood and seriously affects the ability of the atmosphere to remove other pollutants since it reacts with the hydroxyl radicals which normally do this. Another combined effect of pollutants is the formation of photochemical smog when polluted air is trapped at the surface of the earth by a temperature inversion. Reactions between nitrogen oxides and hydrocarbons, initiated by sunlight, form ground-level peroxyacyl nitrates and ozone. These are highly reactive chemicals which cause eye irritation, lung damage and may contribute to lung cancer. They also reduce crop growth and damage materials such as rubber.

Finally, coal mining is still a dangerous job. Mining produces ugly spoil heaps, causes land settlement, alters groundwater flow and pollutes water. Oil extraction can pollute groundwater, and oil spills are enormously damaging to marine and coastal environments.

2.1.5 Avoided concerns related to nuclear power

Nuclear power is in decline as it is no longer popular and is recognised as expensive. There are still areas of concern about nuclear power generation, as noted by the WCED [12] :

- the safe disposal of nuclear waste produced both during the fuel cycle and decommissioning
- the release of radiation following major accidents

In contrast, wind energy does not create any dangerous waste products. No member of the public has been injured by wind energy installations, and there is zero risk of large scale catastrophic accidents being caused by wind turbines.

2.2 Avoided Consumption

2.2.1 Fossil fuel reserves

Recently estimated conventional fuel reserves are as shown below. The accuracy of these data are limited since new resources are found every year and new technologies makes it feasible to recover these resources economically from new locations.

Fuel	Proven Reserves (GTOE) [13]	Life at 1996 Extraction Rates (Years)

Coal and Lignite	630	235
Oil	141	43
Gas	129	66

Table 7: Estimated fossil fuel reserves [14]

Events such as the 1973 and 1979 Middle East oil crises, the 1984 UK miners' strike and the Gulf War in 1991 focused attention on the vulnerability of conventional fuel supplies. The cost of fuels will increase sharply when demand outstrips availability, and the costs of fuels will inevitably rise as reserves are extracted in economic merit order. Gas offers only short term amelioration of greenhouse gas emissions. Developing countries are industrialising largely along similar conventional generation lines to the EU. China, for example, is installing new, mainly coal-fired, plant at an average rate of 300 MW per week. While new reserves continue to be discovered, they cannot keep ahead of demand indefinitely. Current rates of use are approximately 300,000 times greater than the rate at which fossil fuels are naturally created. Conventional fuel use will continue for many years to come but is ultimately unsustainable.

In contrast, wind is an indigenous, secure, sustainable and freely available resource. Wind energy can therefore contribute to security and diversity of energy supply in addition to reducing harmful atmospheric emissions.

2.2.2 Essential uses of fossil fuels

There are many alternative means of generating electricity. Substitution of fossil fuels, especially oil, in the rapidly growing transport sector of energy demand is, as noted earlier, far more problematic. Oil derivatives in the forms of petroleum, diesel and kerosene will remain the principal fuels for land, sea and air transport for several more decades. Longer term alternatives for land and sea transport include batteries, fuel cells and, perhaps the most promising and sustainable option, hydrogen. Wind energy could provide the electricity required to charge batteries and electrolyse water to generate hydrogen on a large scale, but some form of strategic intervention will be required to bring about such fuel switching. An even more essential use of fossil fuels is as petrochemical feedstocks for processes as diverse as the production of plastics and the manufacture of steel. No known substitutes are available. In this context, combustion of these essential materials to generate electricity at relatively low levels of efficiency may be judged to be short-sighted. Wind energy, as part of a portfolio of non-fossil generation technologies, has the potential to prevent a long term "feedstocks crisis".

3 ENVIRONMENTAL EFFECTS

Extensive reference is made throughout this section to the findings of the "ExternE" exercise[15], supported by DG XII of the European Commission and the US Department of Energy, which evaluated the external costs of a variety of energy production methods including wind energy. Public perception of wind farms is equally important but, being determined at least as much by attitude and predisposition as by facts, is more difficult to quantify.

3.1 Amenity

3.1.1 Land use

About 99% of the land area on which a typical wind farm is sited is physically available for use as before. Wind turbine foundations, though about 10 m in diameter, are normally completely buried, permitting any existing agricultural activity to extend right up to the tower base. There is no evidence that wind farms interfere to any greater extent than this with arable or livestock farming. Wind energy is, nonetheless, a relative diffuse primary energy source, but any valid comparisons of land use with other means of generation must take into account the total fuel cycle in each case, as shown in Table 8 below:

Generation Technology	Land Required per GWh for 30 Years (m^2)
Geothermal	404
Wind	**800 - 1335**
Solar Photovoltaic	3237
Solar Thermal	3561
Coal	3642

Table 8: Land required per GWh for 30 years by generation technology[16]**.**

A large proportion of the land area utilised for coal-fired generation is accounted for by mining and transportation activities located far away from the power stations themselves.

The 4300 wind turbines installed in Denmark by the end of 1997 produced as much electricity as the total consumed in Denmark in 1952. Over 7% of the national electricity consumption in Denmark is now supplied by wind energy and the country is well on its way towards the national target of 10% of electricity consumption being supplied by wind energy by the year 2005. This target could now be reached with approximately 1000 state-of-the-art wind turbines due to technological improvements and larger machine sizes. The land area required would be approximately 100 km^2 of which only around 1% would be utilised for the wind turbine foundations [17].

3.1.2 Visual amenity

Wind farms must be in exposed areas in order to be commercially viable. They are therefore visible. The reaction to the sight of a wind farm is highly subjective. Many people see them as a welcome symbol of clean energy whereas as some find them unwelcome additions to the landscape. This subjective nature of the reaction is illustrated by the failure of the ExternE study to quantify an external cost associated with visual impacts.

A survey conducted by AKF in Denmark [18] estimated the costs of sound and visual impact from wind turbines to be minimal - less than ECU 0.0012 per kWh of electricity produced. The survey was primarily based on interviews with 342 persons living close to wind turbines in which they were asked how much they would be willing to pay to get the wind turbines removed. To check the results of the interviews, the prices of 74 houses situated close to wind turbines have been compared with those of similar houses situated elsewhere.

Understanding of the broader environmental benefits of wind energy tends to improve the public reaction to a wind farm. The industry has devoted considerable effort to careful integration of developments into the landscape. Computer-generated photomontages, animations and even fly-throughs, together with mapped zones of visual influence, provide objective predictions of appearance. A 1.5 MW turbine looks little different from a 500 kW machine, so the continuing trend towards larger wind turbines may, paradoxically, reduce the subjective visual effect of a given installed capacity.

It is well documented [19] that the overwhelming majority of visitors to wind farms are favourably impressed, and it is not unknown for developers to bus sceptical local planning officials to a real wind farm with very positive results! Independent opinion polls have confirmed that the fears of some local residents at the planning stage have swung to overwhelming support after commissioning. Surveys from other European countries indicate very similar levels of support.

A typical wind turbine used for large scale grid-connected electricity generation is rated at around 600 kW, is supported on a 40-60 m tower, and has a three bladed upwind rotor with a diameter of 42-48 m. Although the trend towards larger machines is continuing, this configuration is likely to remain the most popular in the market, especially in areas with a high density of population for the following reasons:

- three bladed rotors turn more slowly than two bladed rotors and the sound effect will therefore in general be less
- two bladed rotors appear to tilt with respect to the horizon whereas three bladed rotors appear to revolve and are therefore more calm and pleasant to view
- the general public is becoming accustomed to a norm of appearance

Most wind turbines are today being installed on a tapered tubular steel tower which most people find more aesthetically pleasing than the lattice towers more widely used in the US. Professional designers have been used by several wind turbine manufacturers to enhance the appearance of their machines.
Landscape architects are usually involved in the visual assessments of new projects. The untidy appearance of early US developments has not been, and will not be, either proposed or accepted in the EU.

The effects of the periodic reflection (glinting) or interruption (shadow flicker) of sunlight have been addressed by careful consideration of machine siting and of the surface finish of the blades. These phenomena are entirely predictable and their amelioration is easily integrated into wind farm design at the outset. They only occur during periods of direct sunlight, and are therefore not a problem when the sunlight is diffused by clouds.

The figure below shows an example of the calculation of the shadow flicker effect. This figure has been constructed for Denmark. The results would vary for different countries due to the different allowances for cloud cover and latitude. There are two houses in the picture marked as A and B which are respectively 6 and 7 hub heights away from the turbine in the centre. The diagram shows that House A will experience a shadow from the turbine for 5 hours per year. House B will experience a shadow for up to about 12 hours per year. The seasonal variation is also included in the calculation but is difficult to show without undue complication.

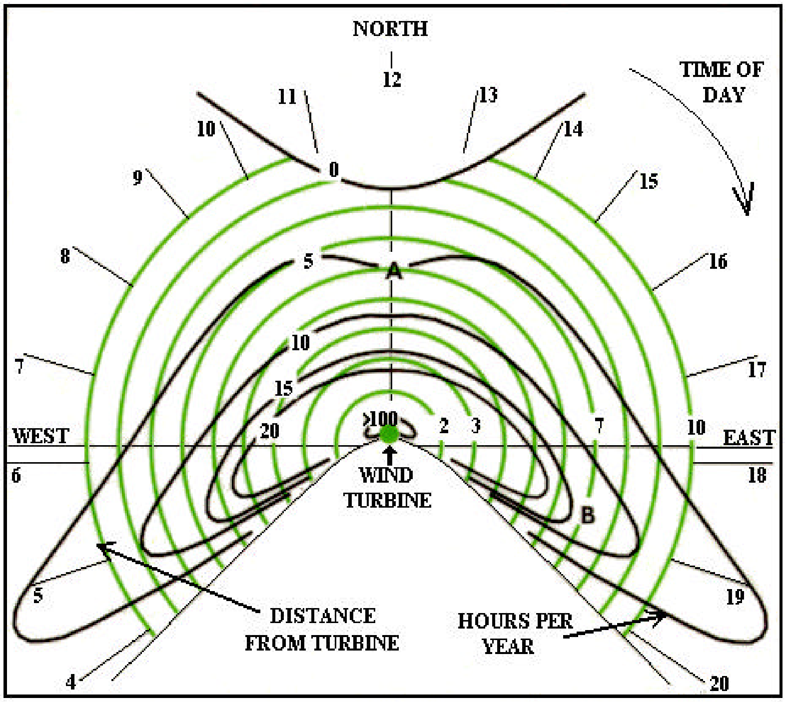

Figure 3 An example of a shadow flicker calculation

A common guideline used in Denmark is a minimum distance of 6-8 rotor diameters between the wind turbine and the closest neighbour. Houses located at a distance of 6 rotor diameters (approx. 260 meters for a 600 kW machine) from a wind turbine in any of the sectors described above will be affected for two periods each of 5 weeks duration per year[20].

3.1.3 Sound

Modern wind turbines are quiet and are becoming even quieter.

In order to assess this statement objectively it is useful to understand something of the physics and methodology of sound. Sound is measured in decibels (dB) using a logarithmic scale. The decibel is a measure of sound pressure level - the magnitude of the pressure variations in the air. An increase of 3 dB is equal to a doubling of the sound pressure and therefore a noticeable change in the sound level. An increase of 10 dB sounds roughly like a doubling of “loudness”. Measurements of environmental sound are made in dB(A) which includes a correction for the sensitivity of the human ear. Formally the measurement of sound requires some additional descriptors: the type of representation and the time over which the sound is measured typically: 1 min, 10 minutes or 1 hour. For a wind turbine these different approaches give very similar results and it is not necessary to discuss them in detail here.

The sound pressure level at a distance of 40 metres from a typical turbine is 50 - 60 dB(A), about the same level as conversational speech. At a house 500 metres away, when the wind is blowing from the turbine towards the house, the sound pressure level will be about 35 dB(A), equivalent to the sounds inside a peaceful house. A farm of ten such wind turbines, with the nearest at a distance of 500 metres would create a sound level of about 42 dB(A) under the same conditions - equivalent to the sounds inside a quiet office. With the wind blowing in the opposite direction the level will be significantly up to 10 dB lower.

When planning a wind turbine development, careful consideration is given to any sound which might be heard outside nearby houses. Inside, the level is likely to be much lower, even with windows open. The potential sound effect is usually assessed by predicting the sounds which will be produced when the wind is blowing from the turbines towards such houses - a conservative assumption. The wind turbine sound increases slightly with wind speed. The sound of the wind in nearby trees and hedgerows, around buildings and over local topography also increases with wind speed, but usually at a faster rate and thus it often masks the sound of the turbine. A very detailed evaluation of the sound from wind turbines in the context of the physical planning has recently been undertaken and reported in the UK [21].

Ten years ago wind turbines were louder than they are today. Much effort has been made to create the present generation of quiet machines through detailed attention to both the design of the blades and to the mechanical parts of the machine. As a result noise is not a problem for modern wind turbines which are carefully sited.

3.1.4 Electromagnetic interference

Experience has shown that careful design of a wind farm will avoid any disturbance to telecommunications systems. It is nevertheless useful to have an appreciation of the issues involved. Radio waves and microwaves are used for a wide variety of communication purposes. Any large, moving structure can produce electromagnetic interference (EMI). Wind turbines can cause EMI by reflection of signals from the rotor blades so that a nearby receiver picks up both a direct and reflected signal.
Interference occurs because the reflected signal is both delayed due to the difference in path length, and Doppler shifted due to the blade motion. EMI is most severe for metallic materials, which are strongly reflecting, and least for wooden blades which are strongly absorbing. Glass reinforced plastic (GRP), which is used in most modern blades, is partially transparent to electromagnetic waves and therefore intermediate in its EMI effect.

The types of civilian and military communication signals which may be affected by EMI include TV and radio broadcasting, microwave and cellular radio communications and various navigational and air traffic control systems. Wind farm developers consult with the relevant civilian and military authorities to determine whether EMI problems are foreseen. Problems affecting microwave links and aviation communication systems should be avoided at this stage. Interference with a small number of domestic television receivers is an occasional problem, but this is normally rectifiable by a range of relatively inexpensive technical measures such as the use of more directional transmitters and/or receivers. Wind turbines and telecommunications systems co-exist happily in many developments throughout the EU.

3.2 Ecology

3.2.1 Birds

Birds often collide with structures which they have difficulty seeing, especially high voltage overhead lines, masts, poles, and windows of buildings. They are also killed by moving vehicles, in particular road traffic. Bird behaviour and mortality rates tend to be both species and site specific. Estimates of annual bird deaths in the Netherlands from various man-made causes [22] are shown overleaf in Figure 4:

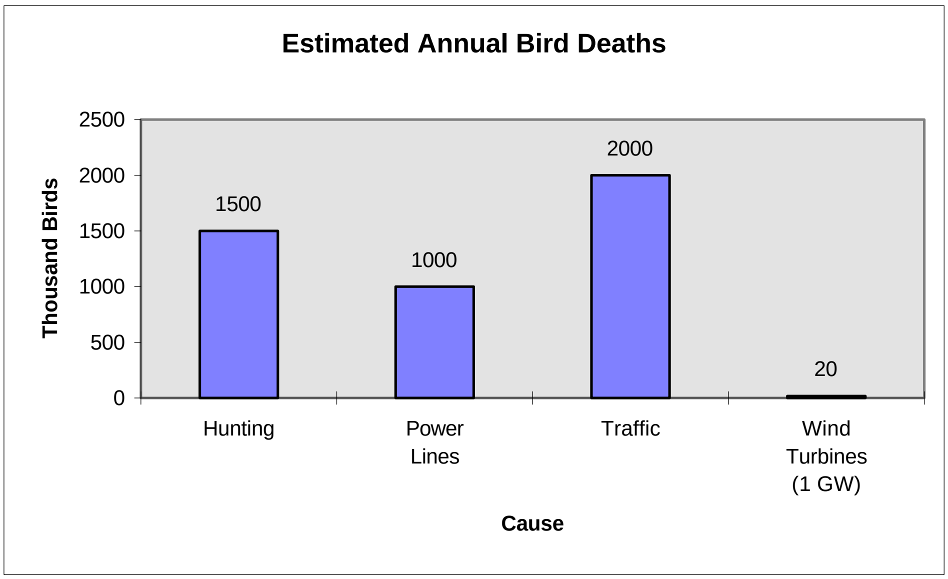

Figure 4: Estimated annual bird deaths in the Netherlands

The estimate for wind turbines is for 1000 MW installed whereas the Netherlands currently has just over 300 MW installed.

More than three hundred times as many birds die from collisions with moving vehicles than with wind turbines and 70 times as many are killed by hunters. These estimates are in line with a study from the Danish Ministry of the Environment which concludes that power lines are a much greater danger to birds than are wind turbines.

Birds are seldom bothered by wind turbines. Radar studies from Tjaereborg in the western part of Denmark, where a 2 MW wind turbine with 60 m rotor diameter is installed, show that birds tend to change their flight route some 100-200 m away from the turbine and pass above or around it at a safe distance. This behaviour has been observed as consistently at night as during the day. In Denmark there are even several examples of falcons nesting in cages mounted on wind turbine towers.

Nonetheless, the issue is taken seriously by the industry and planners alike, and development is normally excluded from bird-sensitive locations such as RAMSAR sites and EU bird protection areas. It has been recommended [23] that careful siting studies should be used to direct wind farms away from critical habitats and topographical features which could cause birds to be concentrated in the area, and that where there is uncertainty about the likely influence of poor visibility and inclement weather conditions, caution should be exercised.

3.2.2 Other ecological effects

Effects on other terrestrial ecosystems result primarily from construction activity, land take and hydrological disruption. The scale of these effects will depend on the type of ecosystem, drainage, construction techniques and timing, and restoration practice. All of these factors and the mitigation measures required should be addressed in the environmental impact assessment process described in the following chapter.

In many locations there will be rapid re-colonisation of the disrupted land by the surrounding system. Evidence suggests that neither wild nor domesticated animals will be affected by a wind farm [24].

3.3 Consumption of Energy and Materials

3.3.1 Energy requirements

Modern wind turbines rapidly recover all the energy spent in manufacturing, installing, maintaining, and finally scrapping them. A typical wind farm repays its energy debt in 3 to 4 months - one of the main results of a detailed life cycle analysis of wind turbines done by the Danish Wind Turbine Manufacturers' Association [25]. The study estimates the energy content in all components of a wind turbine, and the global energy content in all links of the production chain. It employs an "input-output" model of the Danish economy published by the Danish Central Bureau of Statistics. The advantage of this method over engineering calculations is that it can account properly for the energy used by producers of components and manufacturing equipment, buildings etc. in all links of the production chain. The resulting estimated energy requirements of a typical Danish 600 kW wind turbine during its 20 year lifetime are shown below.

Process	Energy (MWh)
Manufacture	528
Installation	137
Operation and Maintenance	215
Scrapping (use)	145
Scrapping (recovered)	-204
Total	**821**

Table 9: Energy requirements of a typical 600 kW wind turbine

The study then estimates the energy recovery time for the wind turbine with respect to the same amount of electrical output per year from a modern coal fired power station as shown below:

Wind turbine site roughness class	Wind turbine electricity production (MWh/year)	Coal-fired plant primary energy consumption (MWh/year)	Wind turbine energy use (from Table 9) (MWh)	Wind turbine energy recovery period (Months)

Class 1	1393	3202	821	3.1
Class 2	1130	2598	821	3.8

Table 10: Energy balance for a typical 600 kW wind turbine

These are conservative estimates as the energy consumption estimates for the coal-fired plant only include direct fuel related costs (energy content of coal and transport). They do not include coal-fired plant construction and operation (which account for over 50% of life-cycle costs) or indirect energy use in the coal firing process. Furthermore, the comparison assumes a thermal efficiency of 45% which is well above the average figure for coal-fired plant in the EU. In general, the wind turbine energy recovery period will be even shorter. Long distance delivery of the wind turbine to site makes very little difference to the above figures. For example, even if a 65 tonne wind turbine has to be shipped 10,000 nautical miles, this will only increase its net energy use by 1.5%.

3.3.2 Material requirements

The most recent and detailed analysis of the material inputs to a wind farm is a case study based on Baix Ebre wind farm in Spain [26] undertaken as part of a life-cycle environmental impact assessment (LCA) of THERMIE for DG XVII [27]. LCA is a generally applicable tool for evaluating the environmental costs of goods and services "from the cradle to the grave". The figures presented below are derived from this work.

Baix Ebre wind farm comprises 27 Ecotècnia 150 kW turbines on a high mountain ridge in Catalonia.

Although the machines are smaller than the current industry standard, widespread interest has been expressed recently in extending the LCA methodology to other case studies.

Table 11 shows the breakdown of weight of material used by wind farm component. The total figures refer to the whole wind farm, whereas the weights per MW installed have been derived by dividing the total figures by 4.05 (the installed capacity of the wind farm in MW). While caution must be exercised with regard to this approach as material inputs may not be strictly proportional to installed capacity, the weights per MW give useful approximate generalised estimates which are more widely applicable.

Wind Farm Component	Total Weight (tons)	Weight per MW (tons/MW)	Proportion (%)
Monitoring masts	<1	<1	-
Turbines	436	108	17
Turbine foundations	1800	444	73
Other infrastructure	241	60	10
Total	**2478**	**612**	**100**

Table 11: Breakdown of materials used by wind farm component.

An alternative breakdown is by material type, as shown below.

Material	Total Weight (tons)	Weight per MW (tons/MW)	Proportion (%)
Concrete	1847	456	74
Steel/Iron	544	134	22
GRP	49	12	2
Copper	12	3	<1
Gravel	14	3	<1
Aluminium	6	<2	<1
Lubricants	<2	<1	<1
PET	<2	<1	<1
PVC	<2	<1	<1
PUR	<1	<1	<1
Others	<<1	<<1	-
Total	**2478**	**612**	**100**

Table 12: Breakdown of materials used by material type.

It is clear from the above data that the material inputs required for a wind farm are dominated by the concrete and reinforcement for the turbine foundations and by the steel from which the turbine towers are fabricated. It is conceivable that a wind farm could, on reaching the end of its operating life, be refurbished by installing new nacelles and rotors on top of the existing towers and foundations.
This would reduce the material inputs required for the “second generation” wind farm by well over 80%. However, as wind farms typically have a design life of 20-25 years, such a procedure has not yet been planned or attempted.

A basic design principle is that weight equals cost, and efforts to reduce the material input to wind turbines themselves continue. Progress in this area is discussed at greater length in Volume 1: Technology.

4 WIND TURBINES AND PLANNING

Most EU Member States have planning requirements which play a critical rôle in the deployment of wind turbines. An exhaustive review of these requirements, especially with respect to environmental impact assessment (EIA), has been carried out under the Altener programme [28].

4.1 Environmental Impact Assessment Procedures

Council Directives 97/11/EC in March 1997 added wind energy proposals to the list of public and private projects that may require assessment for their potential impact on the environment under Annex II of Directive 85/337/EEC. Measures under Directive 97/11/EC are required to have been bought into force by the individual Member States by 14 March 1999.

4.1.1 Regional requirements within the EU

In Denmark [29], Ireland, Germany, France and Finland, EIA is not a requirement for wind energy proposals. In the Netherlands, Sweden, Greece and the United Kingdom, however, legislation has been passed at a national level enabling the relevant authorities to make a request to the developer for the submission of an Environmental Statement. In Italy and Spain the requirement varies from region to region. An Altener project titled "Recommendations for Clear and Specific Guidelines to a Consistent and Desirable Approach to Wind Energy Development" will attempt to provide guidance to Member States that have yet to legislate in this respect.

4.1.2 Best practice

The term "Best Practice" has been adopted to describe the most appropriate approach to be adopted in developing, operating and decommissioning wind energy proposals. The intent of such guidance is to ensure the sensitive development of projects in appropriate locations.

It is beyond the scope of this document to identify and analyse all the relevant Best Practice Guidelines that are available in each of the Member States. However, it should be noted that such documents do exist and should be given due accord by the developer of a wind energy project, whatever the scale, in considering whether an individual proposal is appropriate or otherwise.(33,34) In considering any Best Practice Guidelines, however, regard should first be given to the context of EU policy on sustainable development and the relevant national and local energy, environmental and planning policies that may apply to that proposal.

4.1.3 Site selection

There are no statutory rules governing the site selection procedure, though most Best Practice Guidelines offer advice to potential developers on how to progress. Any site selection and assessment procedure must address the technical, commercial and environmental aspects of the project to determine whether a site is suitable for wind energy development. In addition to technical considerations, account must be taken at an early stage of the requisite planning framework, in particular any landscape, ecological, archaeological or other designations that may apply to the site or be located in close proximity to the proposal. Preliminary consultation with the planning authorities and major consultees should also commence at this stage and, if applicable, the concept of local participation in the project should be considered. Many developers will undertake comparative assessments of several sites at this stage to determine which meet the criteria for further development.

4.1.4 Environmental statements

The purpose of an Environmental Statement (ES) is to specify in detail the proposed project together with a thorough assessment of the impacts it may have. The scope of the ES should be agreed between the developer, the local planning authority and other statutory consultees so that all relevant issues can be considered. Not all Member States require production of an ES. However, it should be noted that in some States where Regulations have not been formulated concerning the formal submission of an ES, detailed information may still be requested on issues surrounding the project and should therefore still be considered by the developer in their consultations with the relevant authorities.

4.2 Mitigation Measures

4.2.1 Planning, construction and operation

In arriving at the final layout for a proposal, consideration should have been taken, where applicable, to the above points and it is likely that certain amendments to the original proposal will have taken place. These may include the moving or removal of certain turbines, the choice and specification of the turbines, the location of the access tracks and electrical connections, and construction scheduling. Thus, through the planning process, mitigation is likely to have taken place to arrive at the most acceptable form of development that satisfies any Conditions of Planning or Obligations that may be imposed.

4.2.2 Decommissioning and site restoration

Decommissioning will include the removal of all above ground elements of the development as a minimum and the restoration of the original site. The methodology for undertaking this should be adequately covered in the Planning Conditions or through a Planning Obligation placed on the project owner. In many cases, however, the majority, if not all, of the decommissioning costs can be recovered from the scrap value of the turbines and copper wiring from the project. Indeed, the ease with which wind turbines can be decommissioned, in comparison with other generating technologies is another significant environmental benefit of wind energy.

4.2.3 Recyclable content

If there is sufficient demand for the secondary raw materials, wind turbines can be regarded as being largely composed of recyclable materials. The principal unresolved issue from an environmental perspective is the recycling of rotor blades. Table 13 below summarises current understanding of the possibilities for the waste management of wind turbines [30].

Components	Recycling	Incineration	Landfill
Rotor blades: GRP/polyester GRP/epoxy	*GRP as filling material for plastics*	*Resin as a reducing agent in blast furnaces with glass fibre as slag, usable in cement works* *Resin as a fuel and glass fibre as a cement additive in cement works* Rotor blades in waste incinerator	Domestic refuse
Foundations and pile foundation	Steel in steelworks Concrete as an aggregate (e.g. for new concrete or road foundations)		Hardcore Pile foundation on-site
Tower: tubular steel or spun concrete	Steel in steelworks Concrete as an aggregate (e.g. for new concrete or road foundations)		
Generator and gear box	Steel in steelworks Alloyed steel in high-grade steelworks Secondary refining of gear oil	Gear oil in waste incinerator (hazardous)	

	Copper in secondary copper plant

Processes in italics are not yet available but at a relatively advanced stage of development.

Table 13: Possibilities for waste management of wind turbines

Recommendations for recyclable design of wind turbines are:

- minimising the number of components and ensuring that they are easy to dismantle
- fabricating of rotor blades without PVC foam
- using recycled concrete scrap as an aggregate in the foundations
- considering easy demolition of the foundations e.g. by incorporating appropriate shot holes
- examining the usability of recycled lubricants
- labelling precise material composition, especially for alloyed steels
- designing rotor blades made of renewable raw materials

5 CONCLUSIONS

"Coal, gas and oil will not be the three kings of the energy world for ever. It is no longer folly to look up to the sun and wind, down into the sea's waves" [31]

The environmental imperative for renewables and energy conservation is now beyond dispute. The developing world is entitled to expect the same living standards in terms of goods and services that we enjoy in the EU, but unless we can lead by example and encourage sustainable energy paths world-wide, global environmental problems will surely worsen. It is possible to design a future European energy system which no longer threatens to change the global climate without invoking the long and short term hazards of nuclear power. Such a system relies on far-reaching energy efficiency measures and substantial use of renewable energies. In this scenario, wind energy would contribute 11.7% of EU energy supply, and amount to 8.5% of installed capacity, by 2050 [32]. The annual cost of such a scenario would be about 50% higher than for a hypothetical reference case based on the best available fossil technologies if external costs are not taken into account.

In November 1997 the European Parliament called on the EU to cut its own greenhouse gas emissions by 15% by 2010 regardless of the outcome of the December 1997 climate change conference in Kyoto. In a resolution adopted by a large majority, MEPs urged EU ministers to adopt a "tougher, binding commitment" to reduce greenhouse gases immediately after Kyoto. The call follows the Commission's publication of a policy paper on climate change last month in which it stated that "the EU proposal is a negotiating position, not a unilateral commitment." (ENDS Daily 16 September). MEPs also called on the Council of Ministers to adopt "as rapidly as possible" a stronger package of measures to meet its 15% target. This should include fiscal measures - such as an energy tax - to reverse global warming, an increase in the share of renewables to be equivalent to 15% of fossil fuel-derived energy and the removal of legislation "contradictory to greenhouse gas emission reduction". The resolution specifically rules out increased use of nuclear power as an option. Wind energy is a sufficiently mature, cost-effective and widely applicable technology to make a significant contribution towards meeting these targets.

This document has reviewed both the environmental costs and benefits of wind energy in some detail. The overwhelming body of evidence from a wide range of authoritative commentators is that the benefits of wind energy greatly outweigh its costs. In cases where quantitative comparisons can be made, the benefits typically outweigh the costs by at least one order of magnitude. The environmental case in favour of wind energy is overwhelming.

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European Commission
Directorate-General for Energy

WIND ENERGY - THE FACTS

Volume 5

MARKET DEVELOPMENT

EXECUTIVE SUMMARY

Brief historical review

Wind energy development in Europe started in the 1970s. It has been supported by both national and EU programmes. After a slow start, the market within the EU is now the world's largest and is expanding rapidly. By the end of 1997 some 4,700 MW had been installed - compared with just 473 MW in 1990.

Present status

Over the last 5 years growth of installed capacity in various countries has ranged from 15 to 75 % per year. Germany installed more than 500 MW in 1995, and the total of new installations in Europe in 1997 is estimated to be 1,265 MW. European manufacturers are the world leaders and supplied 80% of the world market in 1997.

Wind energy targets

Previous targets set by the EWEA and by the Altener Programme's Plan of Action have been exceeded. The original target set by the EWEA was 4,000 MW by the year 2000 and Altener called for some 8,000 MW by 2005. The new EWEA targets are: 8,000 MW by the year 2000, 40,000 MW by 2010, and 100,000 MW by 2020. The figure of 40,000 MW by 2010 is supported by the Commission's White Paper "Renewable Sources of Energy" *(COM (97) 599 final)*. This document provides evidence which suggests that these targets will be achieved.

Market predictions

Predictions indicate that annual installation will increase from today's 1,000 MW per year to some 1,400 MW per year by the turn of the century. By the end of the year 2001 the resulting installed capacity will be some 9,700 MW in Europe. After 2001 the growth rate will increase significantly and a further 7,350 MW will be installed from 2001 to 2005, resulting in almost 17,000 MW by 2005.

Review of wind energy market incentives in Europe

Several ways of supporting wind energy development have been reviewed in this volume. The most common are: public funding of national R&D programmes, direct investment subsidies for the installation of wind turbines, competitive bidding processes such as the British NFFO, and fixed premium pricing of electricity delivered to the public grid. The model with fixed pricing has been shown to be the best way of creating dynamic market development, sound industries and employment within the EU.

In order to meet these targets the following characteristics are required:

- A fair price paid for wind generated electricity which reflects the environmental benefits of producing electricity without the emission of pollutants.
- A well-organised institutional framework.
- Planning regulations which favour wind energy.

Supporting such development in Europe will enable further growth of the strong European Wind Power Industry. It can then benefit from export to the rapidly expanding world market.

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Brief historical review

Modern wind energy use began in the late 1970s as part of a response to the oil crises in 1973 and 1979. Many research and development programmes were started with governmental support. In addition, private sector activity in wind energy slowly emerged. Governments used several different approaches to promote wind energy. While some countries put considerable capital and effort into large R&D programs, others concentrated on creating the right market conditions for deployment of the technology.

The first significant commercial market to appear was in California which, in the period between 1980 and 1986, helped the international wind energy industry to develop. Manufacturers from Denmark, the UK, Germany, Japan and the Netherlands shared the market in California with several American companies. About 15,000 wind turbines were installed in California during the 1980s, of which almost half came from Europe, mainly from Denmark. During that period of time the size of the average wind turbine generator (WTG) increased from 55 kW to 100 kW.

WTGs of many different designs were installed and developed during this period. Significant progress was made in wind turbine technology and the international wind turbine industry matured considerably. The market in California mainly consisted of large wind farms which were installed and operated by private developers.

The years between 1986 - 1990 were difficult for the industry due to the sudden decline in the California market. The wind rush in California was by far the most significant commercial market during the 1980s and its demise caused a number of companies to become bankrupt while others were reorganised with new capital.

This period saw both the number of turbine manufacturers and the number of design concepts decrease. The standard Danish design which consisted of a 3 bladed, upwind, stall regulated machine was optimised and upscaled to 250 kW, thus making turbines more cost effective. Large pitch regulated WTGs were also designed and manufactured. These technical developments made it economically feasible to install wind power in many new markets and initiated the second period of wind power development.

The most notable new markets since 1990 have developed in Germany, India, the UK, the Netherlands, Spain and Sweden. The main issue for wind energy in developed countries is no longer the threat of another oil crisis but rather environmental concern. These issues will be addressed in later sections.

Development in India began as part of a 20 MW DANIDA [1] financed project. Joint ventures were established with local companies and the overall success showed the Indian government that wind power could help solve the shortfall in electrical generation capacity.

The German market has, for several years, been the largest in the world. The high growth in Germany is based on a premium payment for electricity produced by WTGs.

Within the last few years, Spain has become a potential market for large scale development of wind power. A common observation from all of these new markets has been that a guaranteed rate for wind energy creates more stable market conditions compared to project bidding. Similarly, guaranteed energy rates create better conditions for the establishment of a local manufacturing industry.

Over a period of six years (1990-1996) the average WTG size increased from 200 kW to over 500 kW and this trend is continuing. In 1992 the average sizes of WTG installed in Denmark and Germany were 215 kW and 185 kW respectively. These averages increased to 530 kW for both countries in 1995. In the UK the average WTG size was 560 kW in 1996. The introduction, during 1996/97, of megawatt size wind turbines will most likely accelerate this trend for some years to come.

The world market demand has grown from about 200 MW/year in 1990 to a level of 1,300 MW/year in 1995, and this trend is expected to continue to approximately 2,500 MW/year by the turn of the century.

European wind turbine manufacturers have dominated the market for the last five years. Of the 1,292 wind turbine installations recorded in 1996, more than 80% were supplied from European manufacturers. This share is expected to have grown in 1997. The demand side of the wind energy market is also dominated by European countries. In 1996 75% of the world's installations were in Europe.

The international market for wind power has experienced rapid growth since 1988 when it reached its lowest point after the market collapsed in California. There were two major markets in the 1980s which were California and Denmark. Both of these markets went into decline due to changes in investment incentives. Since then, many new markets have been developed with considerable success.

It was not until 1993 that the market exceeded its earlier peak of 420 MW in 1985. However, whereas the 1984 market was dominated by just one country (95% of the total capacity in 1985 was installed in California) the 1993 market had 90% of the installed capacity divided between eight different countries. Figure 1.1 shows the annual global installation rates since 1983 and Figure 1.2 shows the total installed capacity. The present wind farm capacity in Europe, as recorded at the end of 1996 is 3,474 MW for the EU-15 countries with another 22 MW installed in central European countries, Norway and Switzerland.

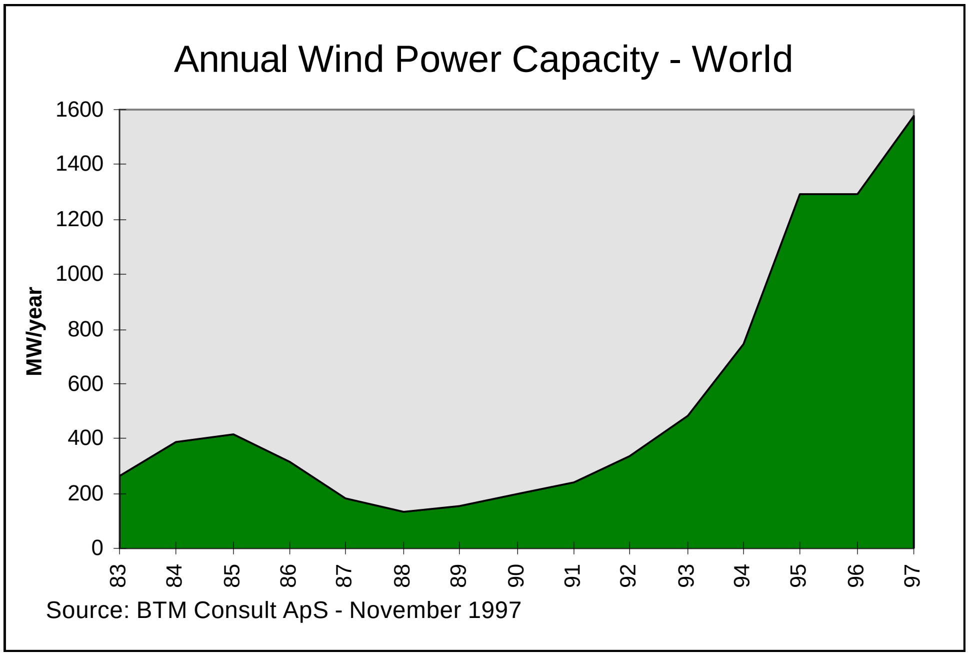

Figure 1.1: Global wind energy development rate MW/year: 1983-1997 (1997 estimate)

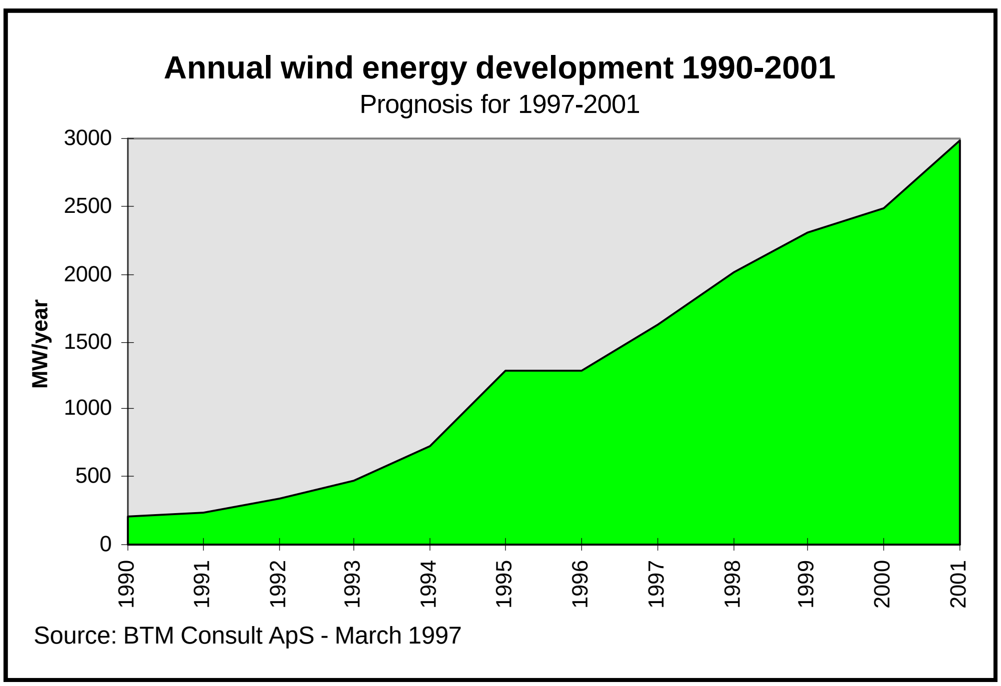

Figure 1.2: Annual global wind energy capacity

1.2 European market development

The European share of the wind energy market has been significant since the late 1970s. In addition, this market has been relatively stable and has seen the industry through times when the international market has been volatile. Table 1.2 shows that the average European market share over the past five years has been about 70%. This market share is expected to continue.

Europe has dominated both the turbine manufacturing industry and the wind farm market over the last five years. Of the 1,292 new installations throughout the world recorded in 1996, more than 80% were supplied by European manufacturers. With the demise of Kenetech in 1996, the largest non-European turbine manufacturer, this share is expected to grow in 1997.

Year	New MW World	Increase %	New MW European	Increase %	European share %
1991	240		193		80 %
1992	338	+ 41 %	218	+ 13 %	64 %
1993	480	+ 42 %	370	+ 70 %	77 %
1994	730	+ 52 %	475	+ 28 %	65 %
1995	1290	+ 77 %	836	+ 76 %	65 %
1996	1292	+0,1 %	967	+ 16 %	75 %
1997 *	1575	+ 18 %	1265	+ 24 %	80 %

Table 1.2: Annual installations and the European market share
* 1997 figures still estimates as per November 1997

2 PRESENT STATUS OF WIND POWER

2.1 Installed capacity

1995 and 1996 have been the best ever years for the wind industry. Both years have seen annual installations of approximately 1,300 MW. This value is about twice the 1994 installation rate. The first six months of 1997 suggest a similar production rate will be maintained.

Countries/regions	Capacity at end of 1995 MW	Installations during 1996 MW	Capacity at end of 1996 MW	Estimate installation during 1997	Estimate Capacity at end of 1997
Denmark	637	200	835	300	1,135
Finland	6.1	1.1	7.2	5	12.2
France	3	2.7	5.7	-	5.7
Germany	1,132	420	1,552	450	2,002
Greece	28	1	29	40	69
Italy	32	38	70	40	110
Rep. Ireland	7	3.6	10.6	40	50.6
Netherlands	249	50	299	50	349
Portugal	8.5	10.6	19.1	10	29.1
Spain	133	116	249	200	449
Sweden	69	34	103	20	123
UK	200	73	273	60	333
Other European countries *1	27	17	43	50	93
European Totals	**2,531**	**967**	**3,496**	**1,265**	**4,761**

Table 2.1: New wind energy installations for 1996 and estimate for 1997 (continues overleaf)

Countries/regions	Capacity at end of 1995 MW	Installations during 1996 MW	Capacity at end of 1996 MW	Estimate installation during 1997	Estimate Capacity at end of 1997
USA	1,591	12	1,596	50	1,646
Canada	21	0.2	21	10	31
Mexico	1.6	-	1.6	-	1.6
S & Central America	10	22	32	30	62
Total America	**1,624**	**34**	**1,651**	**90**	**1,741**
P.R. China	44	35	79	100	179
India *2	576	244	820	50	870
Rest of Asia *3	10.2	2.7	12.9	10	22.9
Asian Totals	**630**	**282**	**912**	**160**	**1,172**
Australia & New Zealand	2.8	3.5	6.3	5	11.3
Pacific Islands *7	0.3	2.7	3	20	23
North Africa *4	8.6	0.15	8.7	10	18.1
**Middle East ***5	8	2.0	10	15	25
**FSU countries ***6	17	1	18	10	28
Total other areas	**36**	**9**	**46**	**60**	**106**
Total new installations		**1,292**		**1,575**	
Global capacity.	**4,821**		**6,104**		**7,679**

Sources: BTM Consult ApS - November 1997 - 1997 figures are estimates, USA figures, source: Paul Gipe Assoc.

Table 2.1: New wind energy installations for 1996 and estimate for 1997

The following are notes on Table 2.1:

1. Other European countries: Belgium, Czech Rep, Slovak Rep, Norway, Austria, Switzerland, East European countries and others. Also includes France for 1997 estimate.
2. The installed capacity in India increased by 244 MW during 1996 although only few wind turbines were sold in India during this year. Much of this capacity was shipped to India in 1995 but not installed and connected to the grid until 1996. This is the main reason why the Danish market share seems low in India during 1996 and high in 1995. It is doubtful whether 820 MW are actually installed and operating at present although this is the official number issued by MNES (Ministry of Non-Conventional Energy Sources) in India. We have only been able to trace around 700 MW. Some sources have indicated that the 820 MW includes approved projects which have not yet been installed.
3. Rest of Asia: Korea, Japan, Malaysia, Indonesia, Thailand, Vietnam.
4. North Africa including: Egypt, Ethiopia, Libya, Tunis, Algeria, Cap Verde, Morocco.
5. Middle East including: Jordan, Syria, Israel, Saudi Arabia, Iran, Iraq (excluding Egypt).
6. FSU countries: Former Soviet Union.

7. Pacific islands: also includes rest of the world not specified under (1-6).

The 1996 installed capacity takes into account decommissioned capacity. The USA has been particularly affected by this characteristic which means that the capacity can decrease as well as increase.

Activities in India during 1996 were much more moderate than expected just a year ago. This has not adversely affected the global result since several other markets have developed more quickly than expected. The five largest markets in 1996 are shown in Table 2.1.2:

Country	**Annual installations 1996 MW**	**Estimate of annual installation 1997 MW**
China	-	100
Germany	420	450
India	244	-
Denmark	200	300
Spain	116	200
UK	73	60
Total	**1,053**	**1,110**

Table 2.1.2: The five largest markets in 1996 and estimate of 1997

Market estimate for 1997

An estimate of the sizes of the five largest markets for 1997 are shown in Table 2.1.2. The significant changes are that India has dropped out of the list, while China shows an encouraging 100 MW of growth. Also, Spain still ranks third on the list.

2.2 Growth in individual markets

Table 2.2 shows the installation of new capacity in the "Top 10" markets in the world over the past five years. Seven EU member states are involved in this list.

Country	Capacity MW	Annual installations - MW/year					Total installations MW	Average growth of Capacity % year
	1991	**1992**	**1993**	**1994**	**1995**	**1996**	**1992-96**	**1992-96**
Germany	110	65	150	307	500	**420**	**1,442**	**70**
India	33	5	22	141	375	**244**	**787**	**90**
USA [1]	1,450	20	80	100	53	**12**	**265**	**3**
Denmark	409	45	29	54	98	**200**	**426**	**15**
Netherlands	83	23	26	22	95	**50**	**216**	**29**
UK	81	38	80	30	40	**73**	**261**	**35**
Spain	15	7	30	23	58	**116**	**234**	**75**
Sweden [2]	9	5	16	10	29	**34**	**94**	**-**
China [2]	3	3	6	18	14	**35**	**76**	**-**
Italy [2]	22	-	-	-	10	**38**	**48**	**-**
Top 10 Totals	**2,215**	**211**	**439**	**704**	**1,273**	**1,222**	**3,780**	
World Totals [1]	**2,223**	**338**	**480**	**730**	**1,290**	**1,292**	**4,130**	**22 %**

Table 2.2: The "Top 10" markets over the past five years (1992-1996)

Notes:

1. The figures for the US are “New installed capacity” which does not take into account the more than 200 MW of older turbines which have been removed.
2. Sweden, China and Italy have not been included in the growth rate column because of their very low 1991 base level.
3. Table 2.1 with 1997 estimates indicate that the growth of installed capacity in 1997 will be some 25%.

Table 2.2 shows that Germany is by far the largest market in Europe. Healthy growth rates are occurring in Spain, the UK and the Netherlands. It is likely that Spain will have a significant increase in installed capacity over the next two years. Italy is expected to become an important market as well.

The total installed wind power capacity in Europe has increased by a factor of three in the period between 1990 and 1996. Figure 2.2 clearly shows that Europe and Asia have become major markets during this period while America (mainly USA) has decreased dramatically.

The market growth in Germany and India have been the two most important elements in this change. Denmark, the UK and the Netherlands have also played an important part in this growth.

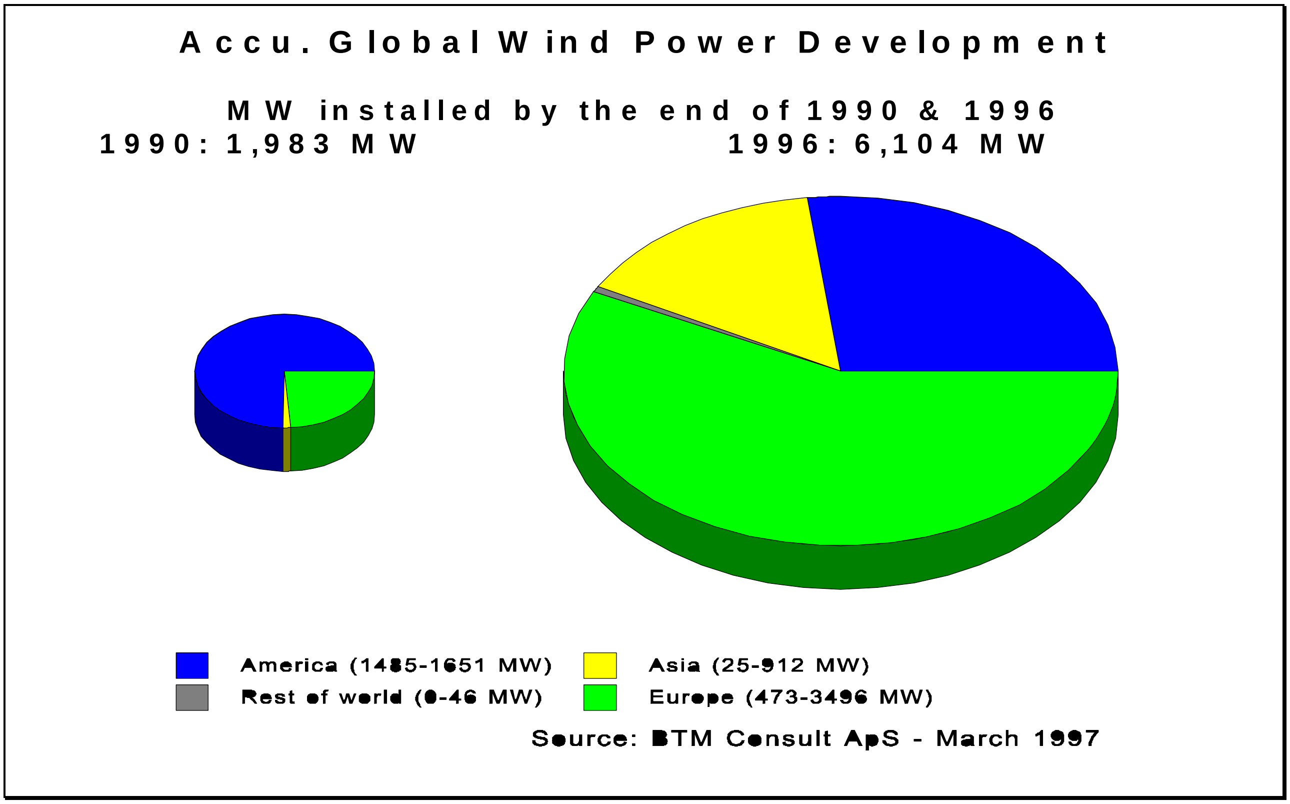

Figure 2.2: Regional breakdown of installed wind power capacity

2.3 Growth in the leading markets

Appendix A shows the pattern of market growth in the main wind farm markets. The countries included have a significant amount of installed capacity and all have been in the emerging and/or mature phase for at least five years. Eight countries are presented which include six from Europe: Germany, Denmark, UK, Spain, the Netherlands and Sweden.

The six European countries accounted for 69% of all new installations in 1996, and their total installed capacity at the end of 1996 was 54% of the world's total. Their share of Europe's installed capacity as of December 1996 was 94%.

3 WIND ENERGY MARKET DESCRIPTION

3.1 Environmental & Energy driven markets

Table 3.1 divides the world wind energy market into two main categories.

These categories are: *'Energy Driven Markets'* (mainly Africa, Asia & Latin America) and *'Environment Driven Markets'* (mainly OECD countries). With the exception of India, Energy Driven Markets are presently small but will become more important.

The Environment Driven Markets are expected to create the main demand in the period 1997-2001. Local manufacturing of wind turbines via joint ventures and the ability and willingness to assist in technology transfer will also become essential factors in both of these markets.

Environment Driven Markets Mainly OECD countries	**Energy Driven Markets** Mainly Africa, Asia and Latin America
Market characteristic No need for additional capacity. Financially able to invest. Wind energy only contributes a very small part of the total energy supply. Political interest and international obligation to reduce CO_2-emission. Wind energy development is <u>not very sensitive</u> to variations in international fuel prices. **EU countries:** Germany, UK, the Netherlands, Denmark, Italy, Ireland, Greece, Spain , Portugal, Finland, Sweden, Austria, (Norway) **America:** USA, Canada, Caribbean Islands **Pacific area:** Australia, New Zealand Some islands in the Pacific Ocean **Asia:** Japan, Taiwan, Malaysia These markets are expected to increase by 6,180 MW of installed wind power capacity between the year 1998-2001. Status at end of 1997 6,449 MW	**Market characteristic** Immediate need for additional energy, especially electricity. Capacity shortfall. Dependent on importation of fossil fuels. In best case self sufficient. Shortage of foreign currency. Moderate to high economic growth (South and East Asia). Higher average increase in population, economic growth and energy consumption than OECD-countries. Need for technology transfer and local production. Very sensitive to variations in international fuel prices. **Africa:** Egypt, Cape Verde, Morocco, Libya **Asia:** India, China, North Korea, Indonesia, Thailand, Vietnam **South America:** Argentina, Brazil, Chile, Bolivia **Central America:** Costa Rica, Mexico, Nicaragua These markets are expected to increase by 2,905 MW of installed wind power capacity between the year 1998-2001. Status at end of 1997: 1,230 MW
Other markets: Between 1998 and 2001 an additional 705 MW is expected to be installed throughout the world. This will mainly be in the Middle East and the FSU countries which are very uncertain markets. Since the FSU countries changed to a market economy, they have experienced a decrease in the energy consumption and they possess large reserves of fossil fuels. The Middle East countries have neither an acute need for additional energy nor national environmental goals. The installation in other markets by the end of 1997 is expected to be approx. 100 MW (estimate).	

Table 3.1: Current and emerging markets for wind energy

These market segments are further described in Table 3.2 where examples are presented. It is expected that new markets will follow development patterns similar to those which have occurred in other countries.

Description of different market segments	Customers	Existing markets and potential newcomers
Privately owned WTGs - 150 kW to 1.5 MW Smaller projects with 1-5 units. Often owned by a group of investors.	Small Cooperatives Farmers Industrial factories	Denmark, the Netherlands Sweden Germany lately also in the USA
Small Commercial wind farms < 5 MW Clusters or small wind farms with 10-20 WTGs, owned by several investors.	Larger Cooperatives Industrial factories Investment groups	Denmark, Germany India, UK
Large Commercial wind farms < 100 MW Large projects established by specialised developers, which build and operate the project.	Independent Power Producers (IPP) Electricity utilities	USA UK Spain Beginning in Germany
Utility owned wind farms in the size 5-100 MW Normally larger projects where the electricity from wind power is part of the generation mix.	Utilities often buy the WTGs directly or via a bidding process. Sometimes as a turn-key project. The market is still rather small globally.	Denmark USA UK China The Netherlands
Joint venture, Type I Sales, assembling and service. Limited technology transfer. Could be the first step to Type II depending on present conditions.	Private companies/factories Industrial entities	Spain India Egypt China
Joint venture, Type II Similar to Type I but also includes local manufacturing and more technology transfer.	Private companies/factories Industrial entities	India Spain USA (still only small scale) China, Egypt
Niche markets Rural areas with only little or no infrastructure.	Development aid and often tailor made assignments. Customers are often international aid organisations.	Developing countries Arctic areas Middle East
Offshore projects Still mainly pilot projects.	R&D with utilities who are expected to become main customers in the future.	Denmark The Netherlands Germany, UK

Table 3.2: Market Segments by customers and size of plants

3.2 Future markets

Different market segments for wind power have evolved over the last 20 years. These segments can be sub-divided in terms of size, customer type and potential for future development. The main categories are listed below:

- Individually owned WTGs in the size between 150 kW to 1.5 MW
- Commercial owned (Cooperatives) wind farms up to 5 MW
- Private developers, wind farms up to 100 MW
- Utility owned wind farms in the size 5-100 MW
- Joint ventures - Type 1: sales, assembling and service of WTGs
- Joint ventures - Type 2: as per Type 1 plus local manufacturing of WTGs
- Niche markets: Stand alone, wind-diesel, fresh water production, telecommunication, ice production and hybrid utilisation
- Offshore projects (emerging market in northern Europe).

Offshore projects

Offshore development has been limited. Recently the Danish Government released a new national energy plan, Energy 21, with a long term (2030) wind target which includes 4,000 MW of offshore wind farms. In July 1997 Danish utilities and the Danish Energy Agency released an assessment of offshore development in Denmark. This assessment predicts that 700 - 800 MW of offshore wind farms will be installed before 2006. In October 1997 the Danish utilities committed themselves to build the first 750 MW for demonstration of Danish offshore wind power. The Dutch authorities have significant plans for utilising their huge offshore potential and there are commercial plans for both Germany and the UK. In the UK a power purchase contract has been let for a 30 MW development in the Thames estuary.

Table 3.3 shows an assessment of the size of the different market segments, based on global wind power development in 1994, 1995 and 1996.

Market segments	% of world market in 1994	% of world market in 1995	% of world market in 1996
Privately owned WTG 150 kW to 1.5 MW	35	52	49
Small commercial wind farms < 5 MW	32	23	21
Large commercial wind farms < 100 MW	22	14	18
Utility owned wind farms < 100 MW	10	10	10
Niche markets	1	1	1

Table 3.3: Market segments in 1994-1996

The future market for global wind power development can be divided into the two different major categories shown in Table 3.1.

Table 3.4 quantifies the market potential for wind power for each of the market segments in these two categories in the year 2001.

Environment Driven Markets	**% of Environment Driven Market**
1. Privately owned WTG: 150 kW to 1.5 MW	7
2. Small Commercial wind farms: < 5 MW	17
3. Large Commercial wind farms: < 100 MW	34
4. Utility owned wind farms: 5-100 MW	34
5. Offshore projects	6
6. Niche markets	2
Total market share (60% of the global market)	100
7. Joint ventures (Type I & II) contributes with:	20

Energy Driven Markets	**% of Energy Driven Market**
1. Privately owned WTG: 150 kW to 1.5 MW	20
2. Small Commercial wind farms: < 5 MW	40
3. Large Commercial wind farms: < 100 MW	17
4. Utility owned wind farms: 5-100 MW	20
5. Offshore projects	0
6. Niche markets	3
Total market share (40% of the global market)	100
7. Joint ventures (Type I & II) contributes with:	80

Table 3.4: Predicted market segment potential in 2001

The global potential for wind energy is estimated to be 7,600 MW of new installed capacity for the four year period 1997-2000. Of this growth 60% (4,600 MW) will be in the Environmental Driven Markets and 40% (3,000 MW) in the Energy Driven Markets.

Activity in the Former Soviet Union and Middle East countries is not included in these figures and is expected to be only about 1% (60-100 MW) of the total.

It is predicted that nearly 50% of the total market between 1997-2000 will be sold via joint venture projects. This segment will be approximately 80% of the Energy Driven Markets and 20% of the Environment Driven Markets.

The latest development during 1996 and 1997 have not - so far - confirmed the forecast of the split between Energy Driven Markets and Environmental Driven Markets. However, we still believe that this will be achieved in the long run. That is based on the resources and the general energy situation in Asia characterised by lack of electricity and rapid economic growth.

4 WIND ENERGY TARGETS

4.1 Background for wind energy development in the EU

Almost 25 years after the first oil crisis, the EU and a number of European countries are still the only governments to have created lasting incentives for renewable energy. These incentives have been instrumental in establishing commercial wind turbine manufacturers and large wind energy utilisation.

The introduction of the European free market (EU-12) in 1988 excluded electricity and gas. Since 1988 the EU has been moving towards a free and transparent market for the electricity sector. In 1996 a free market model was developed for electricity and, according to an EU Directive, must be implemented by all member states before January 1999 and thus increases access to outside suppliers. The level of access increases from 23% in 1999 to 33% in 2003.

The EU free market model does not give any priority to renewable energy. However, individual member states may give priority to renewables and to national issues of strategic importance through the EU's Public Service Obligation (PSO). Extra costs incurred due to any PSO will be shared by all electricity consumers in the country.

The EU-15 presently import 55% of their energy requirements. This dependency is expected to increase to 70 % by 2010. Strategic concerns over energy supply may become an important driver for the exploitation of all indigenous energy sources.

In spite of the lack of firm political goals, there is considerable activity within the European Union initiated by the European Commission, the European Parliament, the Council of Ministers as well as some EU member national governments.

4.2 European wind energy targets

Since the first oil crisis in 1973, many programs to support renewable energy technologies have been established. Most have focused on R&D activities and also on demonstration projects. These activities have taken place on both a national and a European level, by the member countries and by the European Commission. On both levels, targets for renewables, including wind energy, have been set. The most important wind energy targets to date are as follows:

4.2.1 The European Commission's ALTENER program

In 1992 the Commission launched the ALTENER program which was designed to increase the use of renewable energy in the Union.

This program has a renewable energy target of 8% of the total energy use. For reference, at present, renewable energy, mainly hydro, provides 6% of EU member countries energy. The main contributors to the ALTENER 8% target are expected to be wind, biomass and small hydro.

An ALTENER sub-target (3) is 8,000 MW for wind energy which is to be reached by or before 2005. It is likely that wind energy will reach the 8,000 MW goal by 2001, five years earlier than expected.

4.2.2 The EU White Paper on Renewable Energy (1997)

This paper, based on a previous report from the EU Commission: European Energy to 2020 - A scenario approach, EU Commission 1996, and on the TERES 2 report, predicts that 12% of the total primary energy used in Europe can be supplied by renewable energy by 2010. The predictions in these reports [2] suggest that the wind energy installed capacity will be about 50,000 MW by 2020 or 6 to 7% of Europe’s total generation capacity.

The preparatory Green Paper was in a hearing process during 1997. It was approved by the Commission on November 26 and became a White Paper “Renewable Sources of Energy” *(COM (97) 599 final)*. In the White Paper the specific target for wind power is set at 40,000 MW installed capacity by 2010.

Opinion in the wind industry on this EU White Paper is generally favourable. However, while the paper correctly identifies the market barriers to wind, its predictions for wind energy (based on TERES 2) are thought to be too conservative.

According to the EWEA targets, 100,000 MW installed by 2020, wind energy will provide 220 TWh per year. That capacity will produce 18,9 Mtoe equal to 12 % of the total new renewables in 2020. The TERES 2 report expects a contribution from wind energy which is just half of that covered by the EWEA Target 2020.

It is the opinion of the EWEA that wind energy can contribute at least 15-20 % of the total new renewable energy by 2030. This will require the installation of more than 200,000 MW of capacity according to the total mix of renewables in the TERES 2 report.

4.2.3 The Madrid Declaration (1994)

At a conference held in Madrid in March 1994, a broad group of people from the renewable energy community in Europe, along with representatives from the Commission (DG 12 and DG 17) and members of the European Parliament created a “Plan of Action” to promote the development of renewable energy up to the year 2010. This conference produced the Madrid Declaration, which called for a 15%

contribution from renewables by 2010.

The declaration did not give specific figures for the contribution from wind, but the intention was that PV, mini-hydro and wind energy collectively should reach 55,000 MW of installed capacity by 2010.

4.2.4 European Parliament (1997)

In 1997 the European Parliament adopted a new goal for contribution of renewables of 15% which was based on the Mombaur Report. The European Parliament thus has a more ambitious target than the predictions for wind made in the European Commission's White Paper on renewable energy.

4.3 EU member states wind energy targets

Some of the EU member states have national goals for the development of wind energy. The effectiveness of these goals has been varied from country to country. Some countries have experienced problems in fulfilling their goals due to lack of an appropriate institutional framework such as effective planning guidelines. Other countries with very modest goals have large wind markets. Table 4.3 lists wind energy targets for the EU-15 countries.

Country	Wind capacity by end 1997 - MW (Estimate) *	Targets MW	Comments
Austria	17	No targets	Some activity, but electricity prices are too low.
Belgium	7	No specific targets for wind energy	National CO2 plan of 700 MW decentralised capacity by 2005
Denmark	1135	1,500 MW by 2005	Long term target for offshore of 4,000 MW by 2030, of which 540 MW now under negotiation by 2004.
Finland	12	No targets	100 MW by 2000 has been estimated.
France	6	250-500 MW by 2005	Being administrated by EdF
Germany	2,002	2,200 MW by 2000	Targets are set by each Bundesländer. Highest contributions by Schleswig-Holstein and Lower Saxony.
Greece	69	245 MW by 2000 350 MW by 2005	Almost no new installations since 1994, in spite of legislative support for private investment in 1994.
Italy	110	300-600 MW by 2000	Will be exceeded. More than 750 MW has been approved to date.
Rep Ireland	50	170 MW by 1999 470 MW by 2010	After completion of AER-1 a market of 30 MW per year will be stimulated.
Luxembourg	2	No targets	Land resources are limited.
Netherlands	349	1,000 MW by 2000 2,000 MW by 2007 2,800 MW by 2020	The targets after year 2000 will be on offshore locations
Portugal	29	70 MW by 2000	
Spain	449	Targets are set by individual Provinces Galicia, Andalucia and Catalonia possess the majority of the potential	1,200 MW expected by 2000. Potential of more than 6,000 MW has been identified within 5 Provinces
Sweden	123	No targets	Funds available in 1997 to support a further 250 MW
UK	333	No specific target for wind	1,500 MW dnc of all renewables by year 2000

* Note : The figures are rough estimates - November 1997, BTM Consult ApS.

Table 4.3: Targets for wind power development in Europe (EU-15)

Although the targets in Table 4.3 refer to different periods, a summation of the targets and the estimates for those countries without targets, indicate that a total installed capacity of 9,000-12,000 MW will be reached during the period 2000 to 2005.

4.4 EWEA wind energy targets

The European Wind Energy Association (EWEA) introduced its first Strategy Document, "Wind Energy in Europe - Time for Action"[2] in 1991. The goals established in that document were replaced by a new set on the release of the new EWEA Strategy Document 1997. The EWEA goals, together with historical capacity levels for reference, are shown in the table below.

Year	1991 EWEA Targets Installed Capacity MW	1997 EWEA Targets Installed Capacity MW	Annual growth rates (1997 Targets) %/year	Average production rate MW/year
1990	500			
1996		3,500	38	500
1997 estimate		4,761	36	1,265
2000	4,000	8,000	17,5	3,200
2005	11,500		17,5	3,200
2010	25,000	40,000	10	6,000
2020	-	100,000	5	7,500
2030	100,000	-	5	7,500

Table 4.4: Predicted growth in capacity and annual production to 2040

The goals above call for a doubling of the capacity every five years until 2010 and, thereafter, almost a doubling every ten years. The period from 1996 to 2000 represents a doubling in about four years. In comparison during the period 1990-1996 the capacity increased from approximately 500MW to 3,500MW - approximately a doubling every two years.

4.4.1 Are these targets achievable?

The factors that will determine the wind energy market growth in Europe include resources, costs, grid issues, industry limitations and, most importantly, politics. While the first four factors are readily assessed, the political factor is not. Political will is very important for the implementation of wind energy and politics will continue to be a key consideration for the wind energy industry.

4.4.2 Wind Resources in Europe

One European wind resource assessment [3] has judged the land based technical potential [4] for wind energy to be approximately 550 TWh/year for the EU-15. The Norwegian potential increases this figure to 630 TWh/year. Another study carried out for the European Commission by Germanischer Lloyd and Garrad Hassan has assessed the European offshore potential to be large enough to supply all electricity consumption in Europe. The exploitation of this resource will depend strongly on costs. There is strong interest in this area and costs look set to fall sharply. The potential of wind energy in Europe are described in more detail in Volume 1: Technology.

An ultimate goal for Europe of a 20% wind energy contribution or some 400 TWh/year, can be supplied by 200,000 MW with a capacity factor of 23% (based on today's consumption in EU-15 = 2100 TWh/year). This is far less than the European land-based technical potential. The offshore potential add substantial capacity to that on land - see Volume 1: Technology.

It can be concluded that the resource will not be a limitation on the use of wind energy in Europe to the extent of the targets set by the EWEA.

4.4.3 Cost of energy

The cost of a kWh of electricity produced by wind turbines has decreased by a factor of 2.5-3 since 1980. Commercial wind farms with present technology produce electricity in the range of 4-7 cECU/kWh. The cost is mainly dependent on the wind resource. It has been predicted that a reduction potential of at least 50% is achievable over the next 20-30 years. More detailed assessment of the economics of wind energy has been carried out in Volume 2:Costs, Prices and Values.

In general, an increase in manufacturing output results in lower production costs. This cost decrease has been quantified at 15-20 % for each [5] doubling of the installed capacity. Wind turbines consist of many parts and the market supply is a mix of many models and sizes, making such calculations rather complicated. However, applying the production/cost decrease rate as stated above for the period from 1996 - 2010 during which the production rate is likely to double about three times, suggests a cost decrease of 45-60%. The cost reduction potential for wind energy has been assessed by US-DOE (1990) and Risø (1996) and both studies support the values suggested in this report.

The cost reductions of wind energy have been dramatic over the last decade and will continue. The cash cost of wind energy is still higher in markets where gas fired thermal plant dominate. Energy from modern thermal plant using cheap natural gas with no environmental cost component is still much less costly than wind energy because it fail to recognise the environmental benefits of using wind.

4.4.4 Interaction with the grid and present consumption of electricity

It is accepted that a modern electrical grid system will be able to accommodate a penetration of 10-20% by wind power. Forecasts expect the total European consumption to be +3,000 TWh after year 2020. Wind Energy will then contribute with some 20% off all electricity consumption in Europe (EU-15).

Wind energy is unequally distributed over Europe. While some countries will reach the "20% penetration limit" others will not be able to achieve this level due to lack of resources. Assuming no exchange of electricity and present consumption levels, the technical potential (on land) will be reduced from approximately 550 TWh to 340 TWh. This will require about 170,000 MW of wind farm capacity.

However, the liberalisation of the European electricity market is expected to increase the transmission capacity, increase cross-border trading of electricity and bring closer co-operation between countries possessing "comparative advantages" such as wind and hydro-power, particularly from Scandinavia. Therefore, a penetration of 16 -17 % is not unrealistic.

4.4.5 Capacity of the industry

The future installed capacity as projected by EWEA is shown in Table 4.4 together with the required wind turbine production rates. The European wind industry supplied almost 1,000 MW during 1996. The manufacturing capacity at present is over 2,300 MW/year (See Volume 3: Industry and Employment). The production increase shown in Table 4.4 is not an unusual growth rate for an emerging industry. It may, therefore, be concluded that the required expansion of the industry will not be the limiting factor for achieving the goals set by EWEA.

4.4.6 Conclusions on targets

While the EU, national governments and industry associations have set implementation targets for wind energy and the European Commission has heavily supported the R&D and demonstration of wind energy technologies, the lack of effective market regulation will continue to marginalise wind energy. To compete equitably with traditional energy sources, it is necessary to internalise the social and environmental costs of all energy use. This will help establish a fair means of cost comparison between different sources of energy.

The necessary action can include regulatory, financial and taxation instruments. However, until such actions are taken, wind energy will not be exploited throughout Europe to its full potential.

5 MARKET PREDICTIONS

5.1 Prediction methods and data sources

Methods

The predictions made in this report are based on an analysis of the wind energy market over previous years. Recent experience has shown that even when individual markets fail to live up to expectations, market diversity is now so broad that the global market remains stable.

Predictions based on at least five years of market data dampen yearly fluctuations and provide improved accuracy. Recent and expected government policies, which are designed to promote renewable energy uptake, are taken into account.

The predictions are based on individual markets which include countries with:

- National energy plans and governmental support for renewable energy
- Wind energy market growth
- Good wind resources.

The historical development of the leading wind energy markets is shown in Appendix A.

Sources
Data for predictions come from information about installed wind farms and from wind turbine manufacturers from around the world. Important sources include wind power magazines such as Windpower Monthly, Wind Direction, Wind Energie Aktuel, Windkraft Journal, Wind Energy Weekly, DEWI, SERO Journalen. Another important source is the statistical data from The Danish Wind Turbine Manufacturers Association (Vind-Note). BTM Consult ApS also obtain information from a world wide network of consultants, along with government and energy industry contacts.

5.2 Leading markets (1997-2001)

Table 5.2 shows the markets that are predicted to be in the "Top 10" to the year 2001. The countries are ranked in terms of predicted annual installation rates.

Country	1996*	1997 **	1998	1999	2000	2001	Total
India	244	50	300	500	500	500	**1,850**
Germany	420	450	300	300	300	300	**1,650**
Spain	116	200	250	250	250	250	**1,200**
USA	12	50	150	150	200	400	**950**
China	35	100	150	150	150	200	**750**
Denmark	200	300	125	125	150	150	**850**
UK	73	60	100	150	100	100	**510**
Sweden	34	20	50	50	100	100	**320**
Netherlands	50	50	50	50	50	100	**300**
Canada	0,2	10	30	50	100	100	**290**
Total	**1,184**	**1,290**	**1,505**	**1,775**	**1,900**	**2,200**	**8,670**

Table 5.2: Leading markets for the years 1997-2001 Annual installation rates - MW

* 1996 data are actual values ** 1997 figures based on estimate of November 1997

Table 5.2 shows that the "Top 10" countries for the next five years are expected to be the same as for the past five years although rankings have changed. Presently, there are some countries which are not growing as predicted for 1997. However, in the longer term, and more importantly, on a global scale, the market appears to be close to expectations. Countries such as Italy, Greece and Ireland can develop to leading markets within a few years.

5.3 Individual markets

The following comments about some of the individual markets will help to interpret the values in Table 5.2.

- A change of government in **India** in March 1995 was followed by higher interest rates and changes in tax subsidies. This led to a dramatic decline in the Indian wind energy market. The predicted market values for India assume a recovery of the market and then slow but sustained growth. The busiest period for investment in India, due to tax regulations, is the first quarter of the year. 1997 seems to be very disappointing.
- The present market situation in **Germany** is uncertain, as the future of EFL payments is under review. If the present payment of 17.2 pf/kWh is reduced to 12-14 pf/kWh as proposed, the market will decline. In addition, the high wind speed areas are being used up leaving less economic areas to exploit. This will reduce the level of activity. Alternatively, if the current EFL debate ends soon in favour of

wind power, the market will continue to grow.

- Annual development in the **USA** is difficult to predict due to the few large projects now at the planning stage. The market prediction is sensitive for the next few years and will be highly affected if just one or two projects are postponed. Several of these large proposed projects which are located in California, Iowa, Minnesota, Texas, Wyoming and the North Western states were planned to be installed in 1995/96 but have been postponed until 1997/99. The USA has an enormous potential for wind power development if the right conditions are established. The market could therefore be much bigger than estimated. Recent press releases from Enron-Zond, the leading manufacturer in the US, details firm orders for more than 300 MW of capacity (NSP Phase 2 and 3 and in Iowa). These orders suggest a renewal of the wind energy market in the US.
- The development pattern in **Spain** has adopted large projects similar to wind farm projects in the USA, although at a more sustained level. Spain has a vast wind energy potential. Combined with a fairly high fixed payment for electricity [6], the market is very promising. It is still uncertain, as a result of lengthy grid connection discussion, when the development in Galicia will start in earnest, but when it does the conditions should result in very significant growth.
- Development in **Denmark** during 1996 was the highest on record and most recent information indicates that 1997 will probably be as good. The large growth was mainly due to private investors buying into wind turbine projects outside of their area during 1995. This investment opportunity was stopped in 1996 but all projects approved in 1995 will be allowed to proceed. The majority of installed capacity in 1996 and 1997 is based on the 1995 conditions. The future for private development after 1997 is uncertain. As a result, it is expected that the majority of new installations will be by the Danish utilities who have been mandated to install 200 MW (ELSAM: 120 MW, ELKRAFT: 80 MW) between 1996 and the end of 1999. Only a very small part of this goal has already been installed. Previous experience has shown, however, that utility projects are often delayed by 1-2 years.
- The current debate in **Sweden** on decommissioning their nuclear power plants is very likely to benefit wind power development as wind is one of the only options which will not increase CO_2 emissions. It is difficult to estimate how soon this will start to take effect and the current situation for 1997 is not promising. The 30% investment incentive for wind farms was abandoned in 1996 and the payment for wind electricity is not high enough to establish a big market. Recently a new investment subsidy of 15% was launched. The Swedish government is presently working on a new scheme of supporting other technologies to replace the first decommissioned nuclear plant (Barsebäck) which will leave Sweden with a loss of 8-9 TWh/year. It is most likely that wind power will benefit from this new scheme.
- **China** will see a breakthrough this year. For the first time ever a single years installation of new capacity will exceed 100 MW. China is a market where almost all leading manufacturers have installed wind turbines. China have the greatest potential for wind energy in Asia. The national goal for the year 2000 is 600 - 800 MW.
- The **UK** possesses the greatest potential for wind energy in Europe. The NFFO

scheme initiated in 1991 has proved to be a successful model for achieving lower prices by the use of a bidding process. Interest has been great, but many applicants have been unsuccessful with their projects due to fierce competition. After the latest NFFO round projects accounting for some 790 MW were awarded.

Past experience has shown that many projects do not obtain planning approval. Therefore, it is estimated that about half of the awarded projects will be realised in the future. One more NFFO round will be launched before the year 2000. Wind energy has shown to be very competitive compared to other renewables within the NFFO scheme. Also the similar bidding rounds in Scotland and Northern Ireland have been successful. No markets for small individual wind power plants has emerged yet.

5.4 Predicted world wind energy market up to 2001

In this section the data and arguments presented in the foregoing sections are summarised into a single table in which the global market is estimated.

Country (area)	**Total capacity MW**	**New capacity MW**	**Predicted growth 1997-2001**					**New capacity MW**	**Total capacity MW**
	1996	1996	1997	1998	1999	2000	2001	1997-2001	2001
USA	1,596	12	50	150	150	200	400	950	2,546
Canada	21	0	10	30	50	100	100	290	311
Latin America	34	22	30	50	50	100	120	350	384
Total America	**1,651**	**34**	**90**	**230**	**250**	**400**	**620**	**1,590**	**3,241**
Denmark	835	200	300	125	125	150	150	850	1,685
Finland	7	1	5	10	10	10	20	55	62
Germany	1,552	420	450	300	300	300	300	1,650	3,202
Greece	29	1	40	50	50	50	50	240	269
Italy	71	38	40	40	40	40	50	210	281
Rep. Ireland	11	4	40	30	30	30	50	180	191
Netherlands	299	50	50	50	50	50	100	300	599
Portugal	19	11	10	10	10	10	20	60	79
Spain	249	116	200	250	250	250	250	1,200	1,449
Sweden	103	34	20	50	50	100	100	320	423
UK	273	73	60	100	150	100	100	510	783
Other European countries: *1	49	20	50	100	125	125	200	600	649
Total Europe	**3,496**	**967**	**1,265**	**1,115**	**1,190**	**1,215**	**1,390**	**6,175**	**9,671**

Table 5.4: Predicted world wind energy markets to 2001 *continued overleaf*

Country (area)	**Total capacity MW** 1996	**New capacity MW** 1996	1997	1998	**Predicted growth 1997-2001** 1999	2000	2001	**New capacity MW** 1997-2001	**Total capacity MW** 2001
P.R. China	79	35	100	150	150	150	200	750	829
India	820	244	50	300	500	500	500	1,850	2,670
Other Asian countries: *2	13	3	10	50	50	50	75	235	248
Total Asia	**912**	**282**	**160**	**500**	**700**	**700**	**775**	**2,835**	**3,747**
Australia & New Zealand	6	4	5	20	20	20	30	95	101
North Africa *3	9	0	10	100	75	75	75	335	344
Middle East *4	10	2	15	20	30	30	30	125	135
FSU countries *5	18	1	10	10	20	20	50	110	128
Rest of the world	3	3	20	20	20	20	20	100	103
Total other areas	**46**	**9**	**60**	**170**	**165**	**165**	**205**	**765**	**811**
Total new capacity MW/year		**1,292**	1,575	2,015	2,305	2,480	2,990	**11,365**	**17,469**
Installed capacity (MW)	**6,104**		**7,679**	**9,694**	**11,999**	**14,479**	**17,469**		

Source: BTM Consult ApS - March 1997, *) 1997 estimate corrected in November 1997

Table 5.4: Predicted world wind energy markets to 2001

1. Other European countries: Belgium, Czech Rep, Slovak Rep, France, Norway, Austria, Switzerland, other East European countries.
2. Other Asian countries: Korea, Japan, Malaysia, Indonesia, Thailand, Vietnam, etc.
3. North Africa including: Egypt, Ethiopia, Libya, Tunis, Algeria, Morocco
4. Middle East - including : Jordan, Syria, Israel, Saudi Arabia, Iran, Iraq excluding. Egypt
5. FSU countries: Former Soviet Union

The market projections in Table 5.4 are also shown in Figure 5.4.

The market trend experienced from 1990 to 1995 is not expected to continue. This period saw an increase in the annual growth rate from about 15% in 1990 to 34% in 1995. In 1996 it slowed to 26%. Predictions show an annual growth rate of 26% for 1997 which decreases steadily to 21% in 2001.

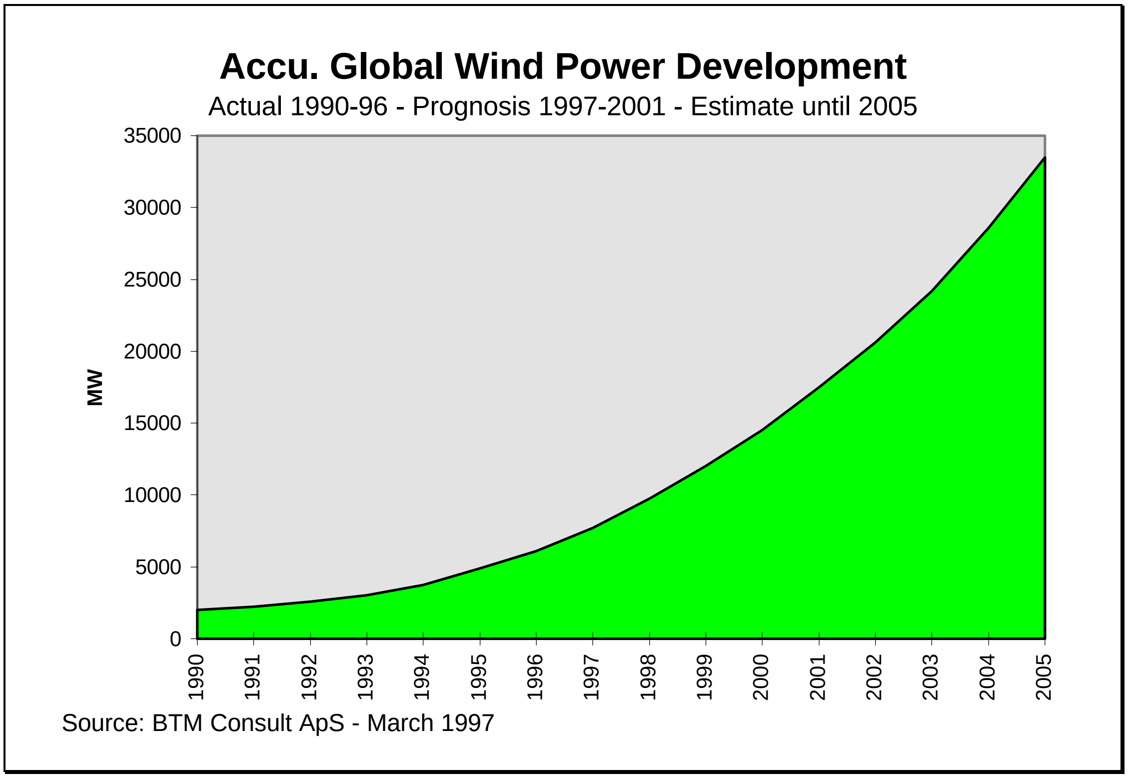

Figure 5.4: Actual and predicted market growth : 1990 - 2000, MW/year

Figure 5.4.1 shows the way in which the global market is expected to be distributed in the year 2001 together with the same information for l996.

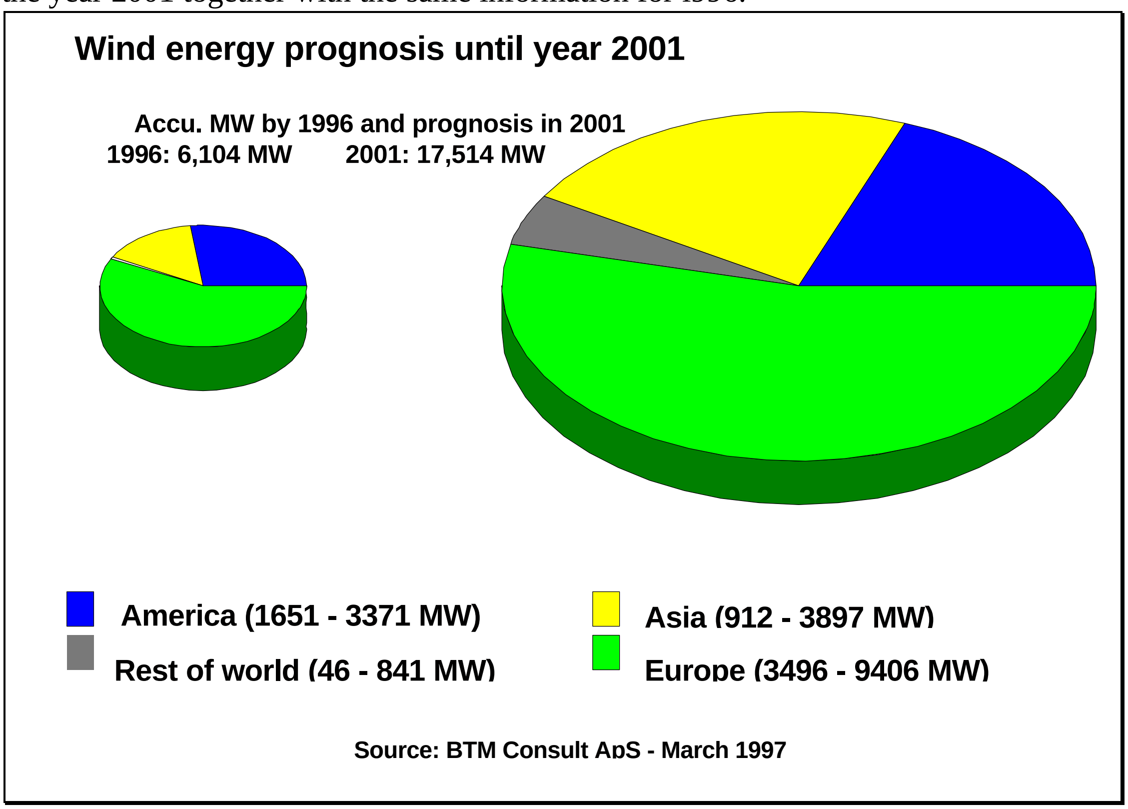

Figure 5.4.1: Regional breakdown of installed capacity in 1996 and predicted for 2001

5.5 Predicted market for the period 2001 - 2005

Table 5.5 shows predictions for the wind energy market for the period of 2001 to 2005. The uncertainty is greater than for the period to 2000 but the figures are nevertheless considered useful.

County (area)	**Total capacity (MW)**	**Predicted growth 2001 - 2005**					**New capacity**	**Total capacity (MW)**
	1996	2001	2002	2003	2004	2005	2001-2005	2005
North America	1617	2967	500	500	700	700	2400	5367
Latin America	34	404	120	200	250	300	870	1274
Total America:	**1651**	**3371**	**620**	**700**	**950**	**1000**	**3270**	**6641**
Denmark	835	1535	150	150	150	150	600	2135
Germany	1552	3052	300	300	400	500	1500	4552
Netherlands	299	599	200	200	250	250	900	1499
Spain	249	1449	200	200	300	300	1000	2449
Sweden	103	433	100	150	250	300	800	1233
UK	273	823	250	250	300	300	1100	1923
Other EU-countries	136	866	150	200	200	300	850	1716
Central Europe + Russia	66	776	100	150	150	200	600	1376
Total Europe	**3514**	**9534**	**1450**	**1600**	**2000**	**2300**	**7350**	**16884**
India	820	2820	500	500	500	500	2000	4820
P. R. China	79	829	300	400	500	500	1700	529
Other Asian	13	248	100	150	150	200	600	848
Total Asia	**912**	**3897**	**900**	**1050**	**1150**	**1200**	**4300**	**8197**
Australia & New Zealand	6	106	30	50	100	100	280	386
Middle East & Africa	19	504	100	150	200	250	700	1204
Rest of the world	3	103	10	15	15	5	55	158
Total others	**28**	**713**	**140**	**215**	**315**	**365**	**1035**	**1748**
World per year			3,110	3,565	4,415	4,865	**15,955**	
Total installed MW	6104	17,514	20,624	24,189	28,604	**33,469**		
Growth rates of total installed capacity			18%	17%	18%	17%		

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Table 5.5: Predicted global wind power development for the period 2001 - 2005

The predictions shown in Table 5.5 are based on a conservative scenario. It is predicted that the annual growth rate will decrease from the 1997 value of 27% until 2002 when it will be about 18% per annum, after which it remains constant.

Based on the predictions presented above the European wind farm installed capacity will develop as follows:

Year	Power
1996	3,500 MW
2001	9,500 MW
2005	17,000 MW

The figures include Central Europe and Former Soviet Union States.

5.5.1 Offshore

It is difficult at present to estimate the offshore share of the installation. However, based on the projects currently under planning and the offshore scheme announced by the Danish Ministry of Energy - 750 MW before 2006, a qualified guess is that some 2-2,500 MW will be offshore installations in year 2005 which accounts for 10-15 % of all wind capacity by 2005.

6 REVIEW OF WIND ENERGY MARKET INCENTIVES IN EUROPE

Turbines have had to compete with mature technologies built on a large scale which have more than 50 years experience and benefit from continuous cost improvements. Cost comparisons on a commercial and equitable basis are therefore difficult.

In the early 1980s, incentives were essential to initiate wind farm development. More recently, the cost of wind turbines has fallen and as a result incentives have been reduced. In some places which have good wind regimes, wind turbines can compete with conventional forms of generation. However, even with cost effective turbines, it is sometimes difficult to compete with public utility systems because of their favourable financing sources - often financed by billing the consumers in advance of the installation of a power plant. Private wind turbine owners and commercial wind farm development companies must borrow money on commercial terms. Often it is difficult to negotiate a loan period which matches the lifetime of the wind turbine. This difficulty is the main reason for the importance of economic incentives for wind farm development and the establishment of the industry.

This problem is not peculiar to wind turbines. It is a common problem in the commercialisation of new technology. The following section reviews some of the most significant models used within the EU and the lessons learned from them.

6.1 Brief characteristics of different schemes and models used within the EU

The development and demonstration of wind energy technology and assistance with market penetration have been supported by national governments and the European Commission since the mid 1970s. The first Joule and Thermie programs were started in 1978 and have continued in the form of 5 year framework programs.

National support programs have been launched in many of the EU member countries. Many different models have been used and the level and continuing flow of support have differed considerably from country to country and over time. The most common models for market stimulation follow:

1. Public funds for R&D programs
2. Public funds for demonstration projects
3. Direct support of investment cost (% of total cost or an amount per kW installed)
4. Support through the use of premium price of electricity from wind turbines (an amount per kWh delivered)
5. Financial incentives - special loans, favourable interest rates, etc.
6. Tax incentives i.e. favourable depreciation
7. Other incentives.

Public funds for R&D and the demonstration of innovative wind technologies have been the most widespread means of stimulation within the EU. They have been used for years at a national level and by the Commission to encourage the development of wind energy within the European Union. EU support for the development of the next generation of MW turbines from the Joule-Thermie Program is a typical example. This development started 7 years ago and the result is that several MW scale machines are available in the market. Substantial national programs have been undertaken in Germany, the UK, the Netherlands and Sweden over the last two decades.

Direct support for private investments has been used to create markets for wind energy and thus to establish a new industry. Direct support for investment costs was used for the first time in Denmark in 1979. The program offered 30 % direct support of the total investment cost, it lasted for 10 years at a declining rate. In 1989, when the subsidy reached 10 %, the program was ended. Since then a similar model has been used in the Netherlands, Sweden and Germany at Länder level, with different rates in each Länder. The Dutch model was based on an amount per kW of installed capacity - adopted from the US market in the mid-eighties - and with some other technical constraints based on the ratio of swept area to installed capacity.

In other cases premium prices for electricity from wind turbines have been used for the stimulation of markets. The most significant use of this model has been in Germany. A law put in force *(Strohmeinspeissegerichte)* in January 1991 required the utilities to pay 90% of the retail consumer price which, at the time, was 0.167 DM. In parallel to this approach, Germany also initiated its “250 MW program”, which gave R&D support to selected turbines in the form of a kWh payment. Initially it was set at 0.08 DM/kWh and later reduced to 0.06 DM/kWh.

These subsidies were limited to 10 years and the recipients were obliged to report the performance of the turbines. This model has been very successful. Other countries which have used the same model are the Netherlands, Sweden and Spain. In Italy, a model using a premium price, based on a license, has been adopted. The UK model, called the Non-Fossil Fuel Obligation, is also based on a premium price, but the projects are selected as a result of a bidding process. This means that there has been competition to obtain contracts, which are valid for 15 years.

Financial incentives in the form of loans have also been used. Again the best example of this incentive is found in Germany, where wind turbine owners have had access to low interest loans, similar to those used for financing agricultural equipment. In Denmark, in the first half of the 1980s, it was possible to get real estate loans for wind turbines and this approach allowed the construction of many of the first turbines. The loan for the wind turbine was an integrated part of the whole loan package for the real estate, including the wind power plant.

A mixture of incentives has often been used to support wind energy development. In Denmark, for example, the incentive package included: a premium price for electricity, a grant towards investment cost and some tax allowances (in particular for co-operatives). Also, a mixture of incentives has been used in Germany and Sweden.

Economic incentives can not stand alone. The general institutional framework must also be in place to secure a successful development of wind energy. This issue will be discussed in Section 6.2. Elements which create a favourable institutional framework are:

- National bodies working on technical approval and certification of wind turbines.
- Careful planning of the implementation of wind turbines, without creating objections from people in the surrounding area.
- Availability of specialist services to the industry has also been shown to be important - as long as they do not possess a monopoly status.

6.2 Lessons learned

The use of market incentives has differed from country to country and from time to time depending on specific needs. The first programs were started some 18 years ago and new ones are still to be launched. It is thus very difficult to make direct comparisons between countries. However, some conclusions can be drawn about the use of incentives to create markets:

- No country can develop a sound industry without having access to results from basic R&D and must have its own R&D institutions.
- National R&D alone does not create markets.
- The use of direct market stimulation through grants and/or through premium prices paid per kWh have both proved effective within the EU.
- The right mixture of incentives reflecting actual and future needs has been crucial for achieving market development.

- Access to the public grid under fair commercial conditions has also been an important issue.
- The key element still missing, on a general European level, is direct payment to reflect the environmental benefit of producing electricity by use of wind energy. This has, to some extent, been included in some national programs.

The use of direct grants to cover a proportion of installation costs has been quite a successful way of supporting development, particularly at the early stages, when it was difficult to obtain sufficient loans for investment in wind turbines. In a typical approach model a National Government allocates funds for this purpose one or two years in advance.

When such a stimulation is successful, it is often followed by a "stop and go" effect because the money is used several months before the end of the year and thereby creates a discontinuity in the market development and creates severe problems for the supply side of the market. The use of direct grants should be carefully considered as part of a general framework which should be in place before the launch of such a program. The "stop and go" effect has been experienced in Sweden and Denmark.

Use of premium prices paid per kWh has been shown to be the most effective tool in stimulating markets. Experiences in both Denmark and Germany demonstrate the efficacy of this approach.

The bidding process, as carried out under the British NFFO scheme, has been shown to be an effective tool for reducing the price of electricity from wind energy by creating fierce competition between manufacturers and developers. That is the good side of "competitive bidding". The negative effects are that, as the bidding process and awarding of contracts takes place once a year or every two years, this leads to a lot of discontinuity in development and makes it very expensive for small enterprises to participate. Another lesson learned from the UK is that without systematic planning in place in the form of general guidelines, which include zoning land areas for wind energy utilisation, competitive bidding results in competition around the same sites - the best sites. This is the principle reason behind objections from the public directed towards wind energy. However, the nature of "competitive bidding" matches the spirit behind an open and competitive European electricity market very well.

From a Government's point of view, it seems more politically responsible to support "kWh's" - they get what they pay for, instead of supporting "kW's". The latter has in some cases lead to manipulation of the subsidy system instead of the minimisation of costs.

Tax subsidies have also been shown to be an efficient tool. However, this model does not encourage the optimisation of technology. Some of the worst examples have been seen in past developments in the US. The public image of wind energy is not enhanced if it is seen as being a means of tax reduction rather than an environmentally friendly way of producing electricity.

Based on the experience described above, an ideal model should include:

- A fair price paid for wind generated electricity which reflects the environmental benefits of producing electricity without the emission of pollutants.
- A well-organised institutional framework.
- Planning regulations which favour wind energy.

6.3 Schemes and models by country within EU-15

Table 6.3 presents a brief review of the stimulation means used by countries within the EU and it can be seen how they are combined in individual markets. Furthermore, remarks about some of the special conditions linked to the incentives are given in the table under comments.

7 CONCLUSIONS

This volume has outlined the history of the wind energy market, summarised the present status and attempted to predict its future. The analysis has shown that the market remains political and that various means have been used in different countries to stimulate it. Some means have been considerably more effective than others and recommendations, based on these experiences, have been made about the most effective means for the future. It is concluded that given the proper conditions and, particularly, the proper recognition of the environmental benefits which are brought by the use of wind energy the market is large and is growing. Although it still remains dominated by the EU countries at present the future projections suggest that this will change in the near future and major export markets for the European industry are developing. The European industry is very well placed to exploit this market as well as to make a major contribution to the supply of the EU market for clean energy provided proper support continues.

Country:	Public funded R&D	Public funded Demo	Support to investment (direct grants)	Premium kWh payment	Financial incentives, loans etc.	Tax incentives	Comments
Austria		x (low)		x (low)			
Belgium		x (utilities)		x (green payment)			
Denmark	x (high)	x (utilities)	x (expired'89)	x (modest)		Cooperatives	The kWh-price is set by law to 85 % of the consumer price
Finland			x				
France				x (Eole 2005)			A 250-500 MW programme managed by EdF recently
Germany	x (high)	x (Länder)	x Länder in the past)	x (high) + "250 MW-pro"	Deutsche Ausgleichbank		The kWh-price is set by law to 90 % of the consumer price
Greece	x	x (utilities)	x	x (modest)	Soft loans		Do not work so far. In spite of new legislation in 1994.
Italy	x (utilities)	x (utilities)		x (licenses)	GEPI		A high start payment declining after 8 years.
Rep. Ireland	x	x	x (AER)	x (AER)			
Luxembourg				x			Premium paid for CO2 reduction and for capacity credit
Netherlands	x (high)	x	x (expired)	x	Green funds	"free depreciation"	
Portugal	x	x	x	x (low)			Payment to IPP's regulated by law.
Spain	x	x (P.E.R 81)		x	?		Tariffs regulated each 5 year
Sweden	x (high)	x (utilities)	x (15% today)	(clean energy premium.)			
UK	x (high)	x		x (NFFO)			The NFFO-schemes have created very low prices

As of September 1997, the "shaded" countries have shown most successful by their use of incentives. All have installed> 50 MW/year in the past.

Table 6.3: Means of stimulation of wind energy in the EU-15.

8 REFERENCES AND NOTES

1 Danish International Development Assistance

2 In the “Best Practice” Scenario of the TERES II report, the contribution from renewable energy by 2020 comes to a potential to be utilised of 228 Mtoe of which wind power will cover 4,4 % equal to approx. 116 TWh calling for about 50,000 MW of installed capacity.

3 Wijk & Coelingh, Utrecht University, 1993.

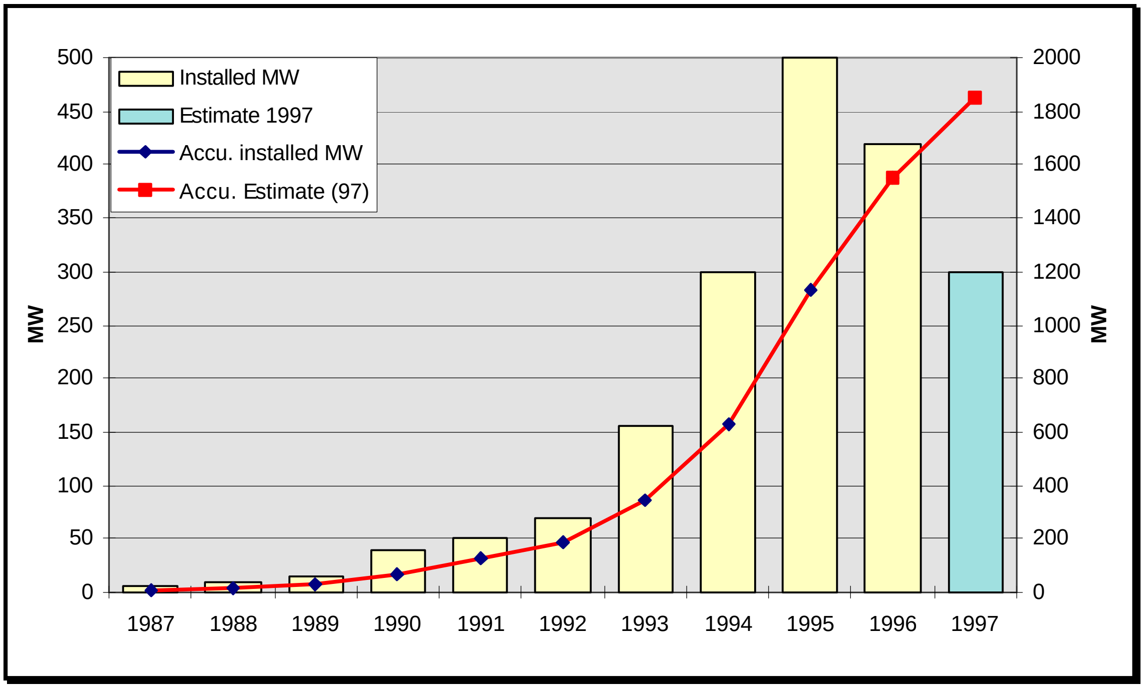
4 The technical potential are defined as, 4-10 % of available land area swept with average wind speeds higher than 5,5 m/s 10 above ground level.

5 Boston Consulting Group.

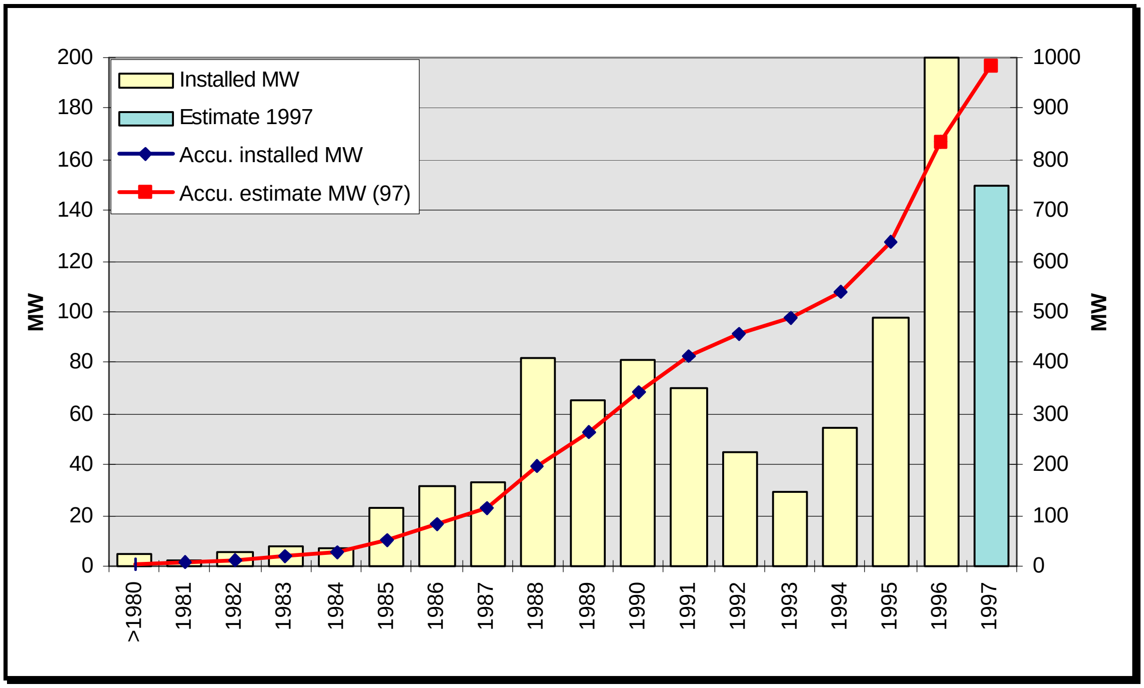
6 This is presently not the case in the USA.

APPENDIX A

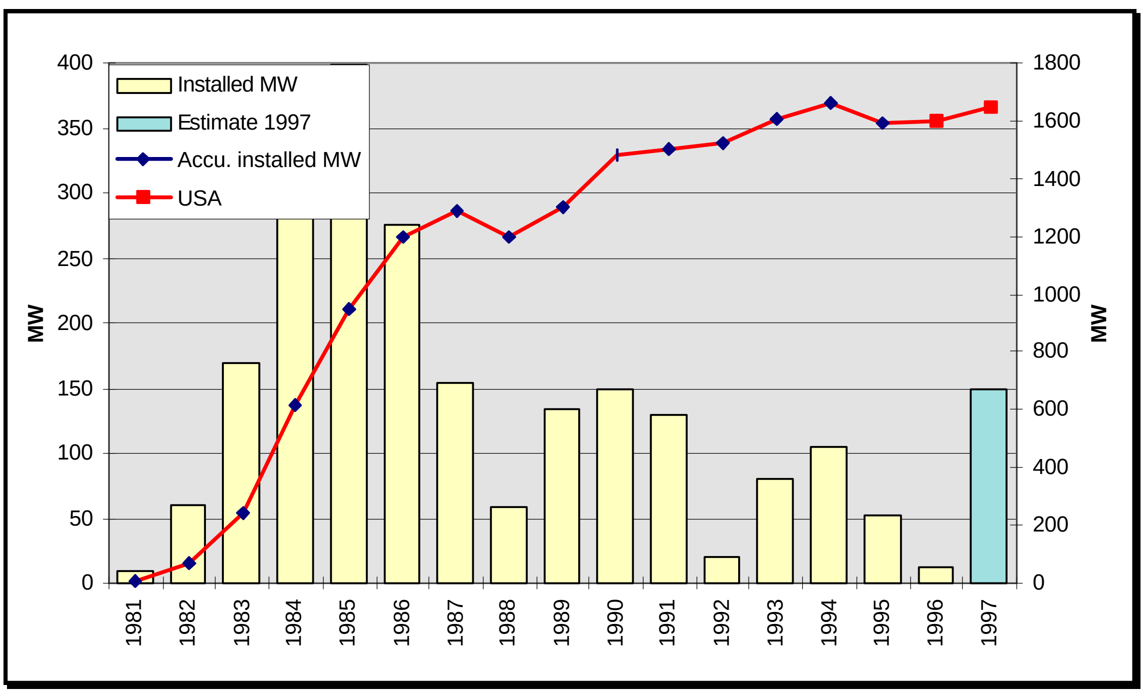
GROWTH OF WIND ENERGY IN ACTIVE COUNTRIES



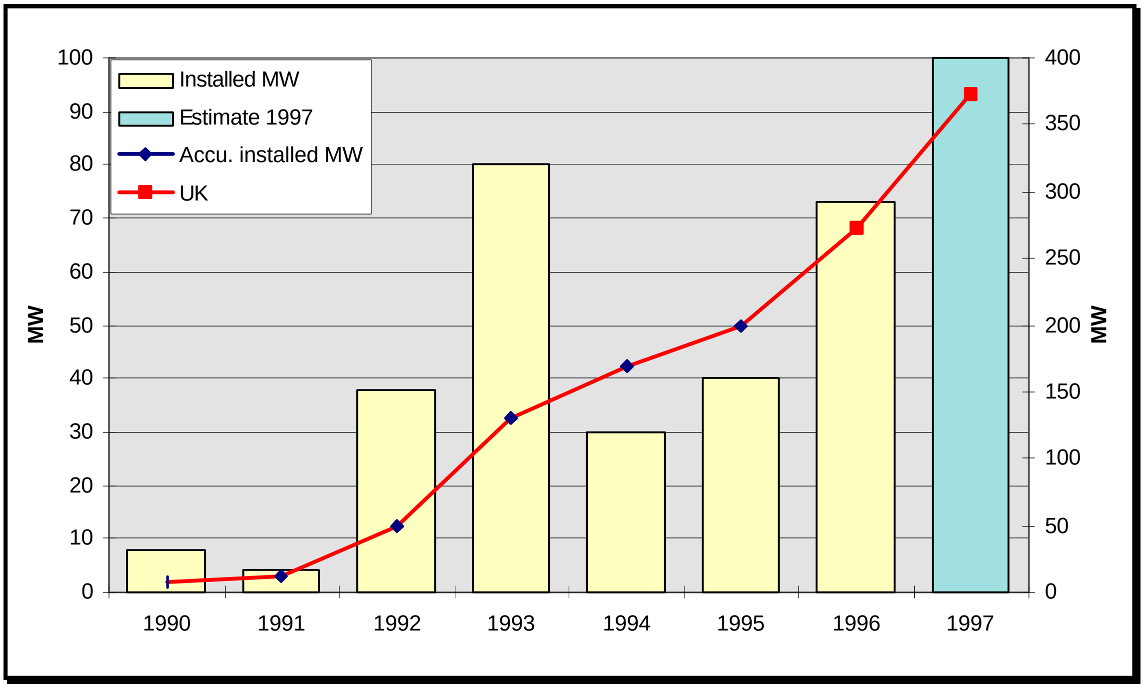
Installed capacity in Germany 1987-1996



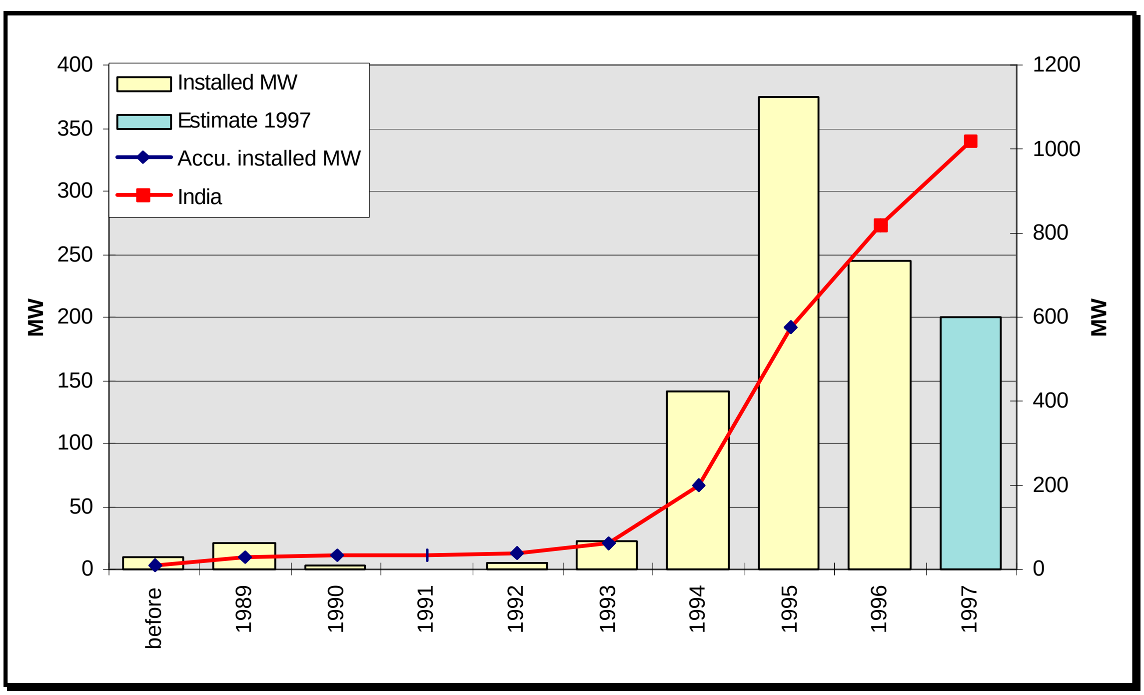
Installed capacity in Denmark 1980-1996



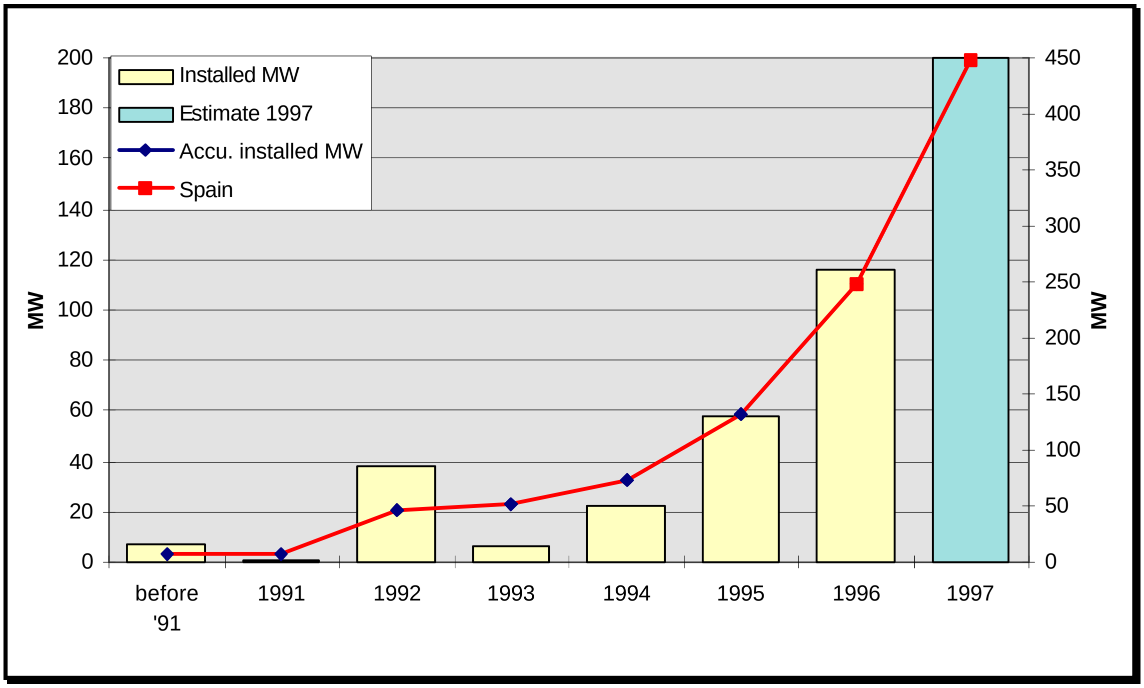
Installed capacity in the USA 1981-1996



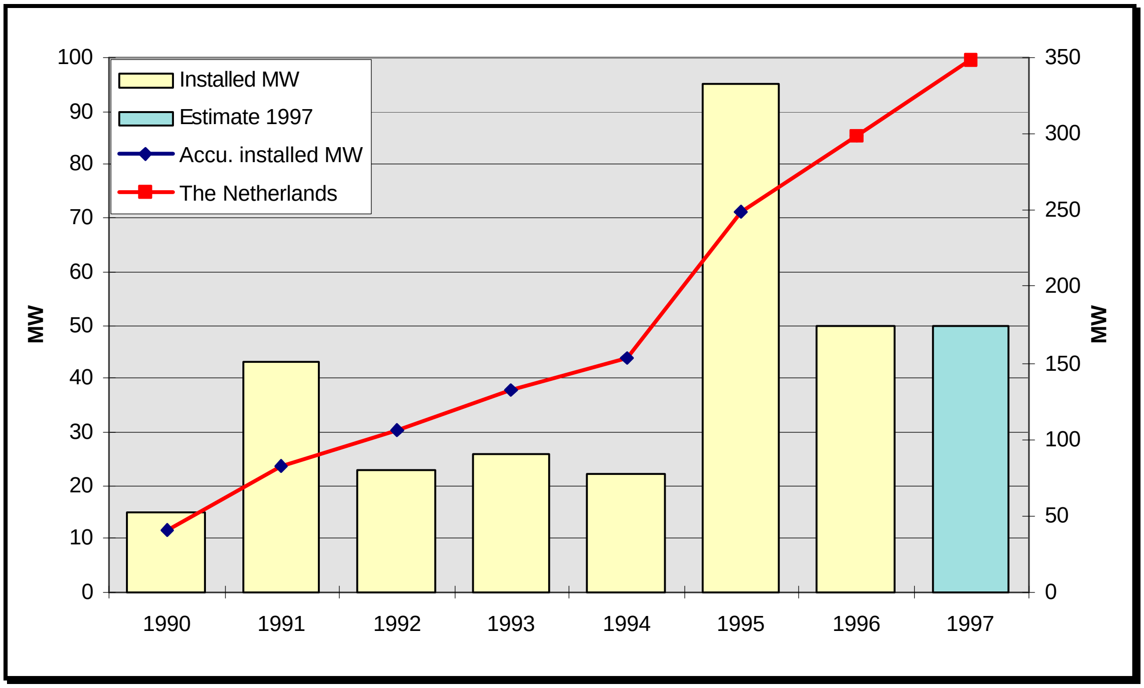
Installed capacity in the UK 1990-1996



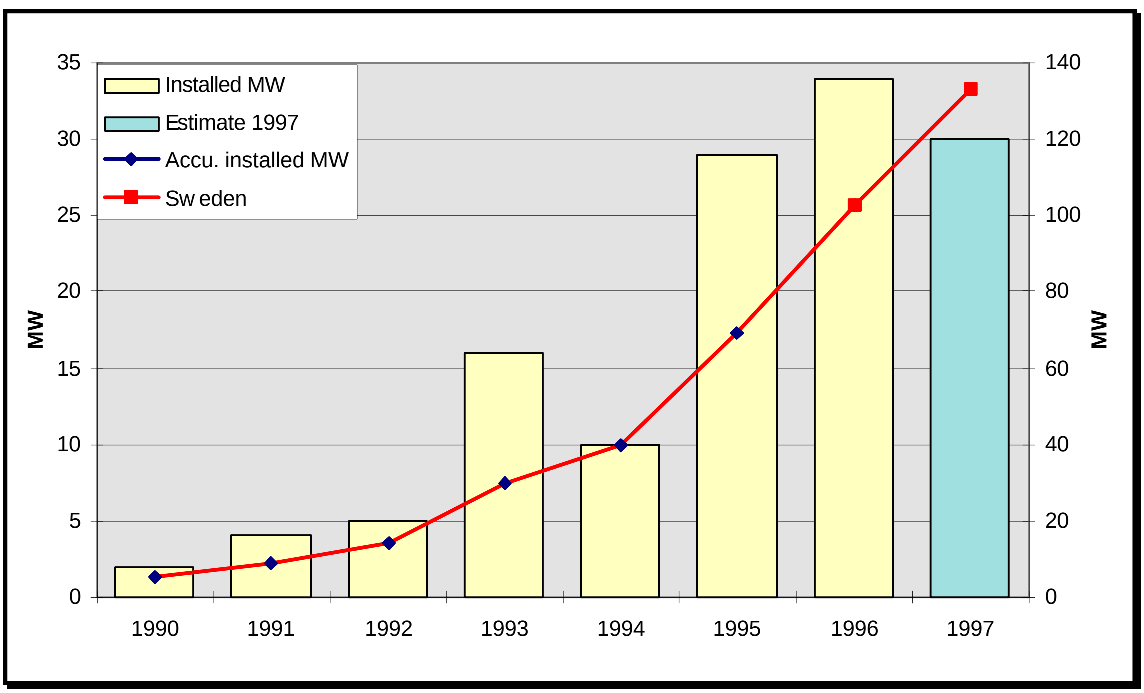
Installed capacity in India 1989-1996



Installed capacity in Spain 1991-1996



Installed capacity in The Netherlands 1990-1996



Installed capacity in Sweden 1990-1996