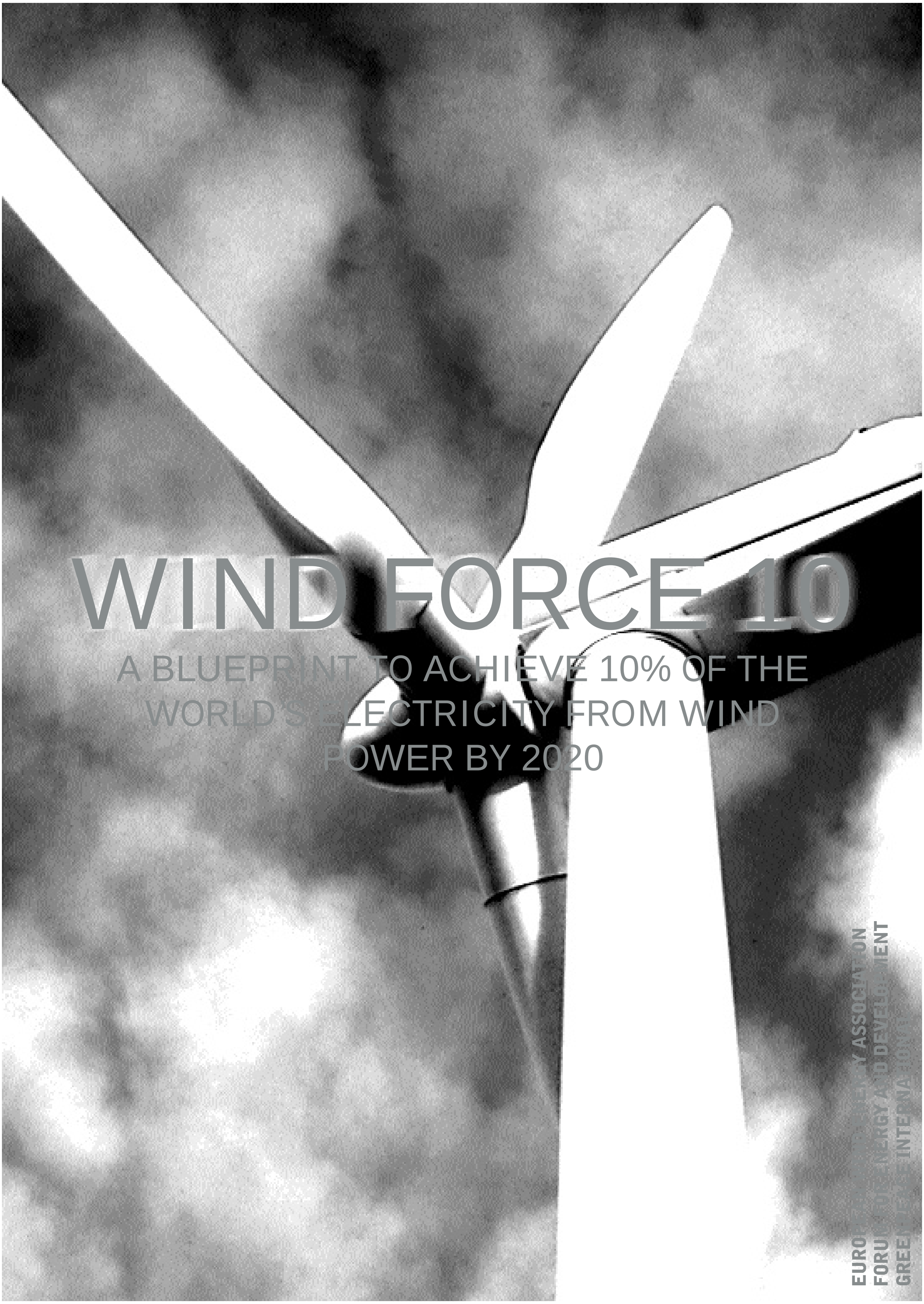

WIND FORCE 10

A BLUEPRINT TO ACHIEVE 10% OF THE WORLD'S ELECTRICITY FROM WIND POWER BY 2020

EUROPEAN WIND ENERGY ASSOCIATION
FORUM FOR ENERGY AND DEVELOPMENT
GREENPEACE INTERNATIONAL

1. INTRODUCTION

Wind power today is a success story supplying electricity to millions of people, employing tens of thousands of people and generating billions of dollars revenue. The pace of change and progress has been rapid for such a young industry.

The benefits of wind power are compelling; environmental protection, economic growth job creation, diversity of supply, rapid deployment, technology transfer and innovation. The fuel is free, abundant and inexhaustible.

Yet these benefits remain largely untapped; most energy decisions taken today overlook wind power, and it faces many obstacles and barriers.

On climate change, an emerging international consensus states that business-as-usual is not an option, that the world must move into a clean energy economy. And some argue that tackling climate change is too daunting a challenge, that change is somehow too costly for economies and industry. In this battleground for solutions, wind power is a premier choice to help counter deadlock and delay – an affordable, feasible, mainstream global power force that is able to substitute for fossil fuels.

We have produced this report in order to update our understanding of the contribution that wind power can make to the world – it is deliberately conservative. The report is a practical blueprint to show that wind power is capable of supplying 10% of the world's electricity within two decades, even if we double our overall electricity use in that time.

The collaboration of our organisations highlights the triple benefits that wind energy offers the world; for the environment, for industry and for development.

Reports are a useful guide, but it is people who change the world by their actions. We encourage politicians and policymakers, global citizens, energy officials, companies, investors and other interested parties to support wind power by taking concrete decisions that will help ensure the 10% target is achieved, and to harness the true force of wind for our common good.

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October 1999

Global Status of Wind Power

Wind power is the most advanced and commercially available of renewable energy technologies. A totally natural source it provides power which is both pollution-free and unlikely ever to run out. In recent years it has been the world's fastest growing energy source.

By the end of 1998, more than 10,000 MW of electricity-generating wind turbines were operating in almost fifty countries around the world. Over the past six years the average annual growth in sales of wind turbines has been 40%.

The most successful markets for wind energy in recent years have been in Europe, particularly Denmark, Germany and Spain. There has also been an upsurge in the use of the technology in the United States, as well as in many developing countries, including India, China, and South America. Wind energy is successful in a diverse range of economies and geographical terrain.

Wind power is also among the cheapest of the renewable energy sources. At good wind sites it is already fully competitive with new traditional fossil fuel and nuclear generation. Its cost also continues to fall as the technology improves and the use of individual sites is maximised.

In recognition of its environmental advantages, many countries have supported wind energy development with government-backed incentives. The aim of these has been to stimulate the market, reduce costs and compensate for the unfair advantage currently held by conventional fuels, for example through state subsidies. A range of market stimulation mechanisms have been used in different countries.

Support for research and development initiatives and fair access for wind power generators to the electricity grid are also important ingredients for the technology's continuing success.

Wind Resources and Electricity Demand

A number of scientific assessments brought together in this report have shown that the world's wind resources are extremely large and well spread throughout six continents. The total available wind resource in the world today that is technically recoverable is 53,000 Terawatt hours per year – about four times bigger than the world's entire electricity consumption in 1998.

The report makes clear that the world's wind resources are unlikely to ever be a limiting factor in the utilisation of wind power for electricity production. Even with wind power generating 10% of the world's electricity by 2020, this still leaves most of the resource untapped.

Development of offshore wind sites, expected to take off in Europe in the first years of the next century, contributes further potential for satisfying electricity demand.

In Europe, the combined wind resource both on land and out to sea will be enough to meet over 20% of the anticipated electricity demand in 2020. Improved technology and cheaper foundations could increase this figure significantly, especially from offshore schemes.

The electricity grid is perfectly capable of accepting large quantities of intermittent wind-powered electricity. In Denmark Government plans are for wind energy to account for 50% of electricity by 2030. Around the world, however, a safe assumption is that 20% is an appropriate average figure for the potential penetration of wind power into national grid systems.

The IEA predicts that the world will double its electricity consumption by 2020 under business as usual. Growing future demand for electricity means that wind power will need to generate about 2,500 - 3,000 Terawatt hours of electricity per year if it is to meet 10% of the world's electricity demand within 20 years.

The 10% Target

On current expectations, wind power is expected to grow at an annual rate of 20% between 1998 and 2003, resulting in a total of 33,400 MW of installed capacity around the world by the end of that period. To meet the 10% target, 30% annual growth from 2004 to 2010 is required, resulting in a total of 181,000 MW installed.

From 2010 onwards, wind power annual growth rates of 20% will result in a total of 1.2 million MW being installed by the end of the year 2020. This will generate 2,966 Terawatt hours of electricity, equivalent to 10.85% of the expected world consumption of electricity. By 2040, wind power could be supplying more than 20% of the world's electricity.

The growth in wind power will be distributed around the world, but the fastest rate of development is expected to be in Europe, North America and China.

The parameters used as a basis for the analysis are:

- Data from historical figures since 1990 and information from the world's leading companies in the market today.

- Exploitable wind potential and levels of electricity consumption in different regions of the world, and conservative estimates of regional penetration limitations.

- An analysis of "progress ratios" and improvements in the technology shows that the wind energy industry is capable of expanding at this fast rate. Wind turbines have been steadily increasing in both power output and efficiency, trends which are expected to continue.

Investment, costs and employment
The annual investment requirements of achieving 10% of the world's electricity from wind energy will be US$ 3billion in 1999, reaching a peak of $78 billion in 2020. These figures are a fraction of overall global energy investments, which averaged $170-200 billion per year in the 1990s. Of course this fraction will increase relatively, as wind power becomes a major element of the electricity sector.

The economics of wind power are compelling. The cost of building and operating wind turbines has already fallen dramatically. In Denmark, the cost of wind energy fell by two thirds between 1981 and 1995.

This study indicates that the costs of wind-powered electricity will further decrease from today's 4.7 UScents/kWh to a level below 3 US cents/kWh by 2013 – only 14 years ahead. By 2020, the figure will have fallen to just 2.5 UScents per unit of electricity produced. This will make wind power competitive with all today's new generating technologies, including large scale hydro.

The employment implications of the 10% target are significant; more than 1.7 million jobs will be created around the world in both manufacture and installation.

The Environmental Benefits of the 10% target
Annual savings of CO2 will be 69 million tonnes in 2005, 267 million tonnes in 2010,and 1,780 million tonnes in 2020.

Between 1999 and 2010, there is a cumulative reduction of 1,120 million tonnes of CO2, and between 2010 and 2020, a cumulative reduction of 9,530 million tonnes of CO2.

Policy Recommendations
In order to achieve 10% wind power the three organisations which have commissioned this report consider that a number of key political actions are required.

- Firstly, it is essential to establish firm targets for wind power in every country around the world where it has potential.

- Secondly, the inherent barriers and subsidies for other fuel sources which currently penalise renewable sources must be removed.

- Thirdly, a variety of legally enforced mechanisms must be implemented which secure and accelerate the new market for wind energy.

The basic analysis in this report was carried out by BTM Consult, an independent Danish consultancy specialising in wind energy.

The aim of the study has been to assess the technical, economic and resource implications for a penetration of wind power into the global electricity system equal to 10% of total future demand. Furthermore, the intention has been to work out whether a 10% penetration might be possible within two decades.

The methodology used on this study explores the following sequence of questions:

- Are the world's wind resources large enough and are they appropriately distributed geographically to achieve 10% penetration?
- What level of electricity output will be required and can this be accommodated in the existing grid system?
- Is wind energy technology mature enough to meet this challenge? What is its technical and cost profile?
- With the current status of the wind power industry, is it feasible to satisfy a substantially enlarged demand? What growth rates will be required over the next two decades?

An earlier study was carried out by BTM Consult for the Danish Forum for Energy & Development in 1998. This has been the model for the present more detailed analysis. The previous study worked with two different electricity demand scenarios for approaching 10 % penetration. In this report only one parameter of future demand for electricity has been taken from the International Energy Agency's 1998 projection, a conservative projection which assumes "business as usual", where electricity consumption doubles.

An important point to note is that the future capacity of wind power has been distributed around the regions of the world independently of the political climate in support of renewables, and solely on the basis of future demand for electricity and taking into account that appropriate resources are available in the respective regions.

The report also compares the development of other new technologies by using so-called "learning curve theory". Because of its modular nature, wind power can benefit significantly from such "learning curve effects", and thereby create an "internal dynamic". This means that a high initial penetration level can contribute to technological/economic progress, in turn justifying an expectation of further progress and enabling a very high eventual level of development. For this reason the penetration curve has been extended to 2040, by which time a saturation level will have been achieved.

For wind power to achieve 10 % penetration by 2020, a manufacturing capacity of 150,000 MW/year has to be established – about sixty times that of 1998. If this manufacturing capacity were maintained beyond 2020 it would open up the potential for an even higher penetration by 2040. By that time 3,000 GW of wind turbines would be in operation.

Penetration of wind energy beyond 2020 has not been assessed in detail in terms of implementation constraints. However, if wind power can fulfil the requirements of this scenario up to 2020, it is likely that development will continue, and with a marginal additional cost of absorption into the utility system.

The BTM Consult analysis does not evaluate or recommend any of the political initiatives required to support this 10 % penetration, such as regulation, market stimulation and development incentives, but Chapter 2 does include a review of market regulation methods currently used in the leading wind power markets. The three organisations have recommended policy changed required to meet the 10% target.

Finally, it has to be emphasised that the BTM Consult analysis is not a long-term forecast. Nor is it a prediction, as the study is rooted in real world experiences and successes of the wind industry today. It is a feasibility study for future scenarios taking into account the essential physical limitations for large scale development of wind power, and it assesses and compares actual industrial growth patterns seen in the wind power sector so far with those in other industrial/technological developments during this century. The actual development will to a large extent be determined by political initiatives taken at a broad global level. Other generation technologies launched in this century have achieved a high penetration in a relatively short time-scale, for example large scale hydro and nuclear, which are respectively now at a global level of 16 and 19%.

OTHER GENERATION TECHNOLOGIES LAUNCHED IN THIS CENTURY HAVE ACHIEVED A HIGH PENETRATION IN A RELATIVELY SHORT TIME-SCALE

Wind power has been the energy success story of the last decade of the twentieth century. Compared with other renewable sources it has been expanding at an astonishing rate. During 1998, yet again, it was the fastest growing energy source of all.

By the end of 1998 an installed capacity of more than 10,000 Megawatts (MW) of electricity-generating wind turbines was up and running in almost fifty countries. This compares with just 2,000 MW at the beginning of the 1990s *(see Figure 2-1)*.

Around the world, in 1998, over 2,500 MW of new wind capacity was connected to the grid. This represented an impressive 66% increase over the previous year's figure. All told, these turbines produce some 20 billion kilowatt hours of electricity, already enough to satisfy about 0.15% of the world's total demand for power. The turnover of the global wind turbine industry during 1998 was more than US$ 2.5 billion.

Expansion has been fastest in Europe, which leads the world in manufacturing and developing the technology. But every continent has now begun to experience the benefits of a means of power production that brings none of the environmental threats which accompany the burning of fossil fuels or exploiting nuclear energy. In Asia, South America, and Australia, wind turbines are being built in widely ranging political/economic situations and across a broad range of geographical terrain.

The detailed figures for installed wind energy capacity in all countries or regions of the world at the end of both 1997 and 1998 are given in Appendix 7.

As important as the total capacity now achieved by wind energy is the rate of expansion in recent years. Over the past six years the average growth in sales of wind turbines has been 40% *(see Table 2-1)*, an impressive record when compared with other technological developments. This level of growth matches that of the booming information technology sector.

Although figures vary, the average rate of expansion in the "top ten" wind energy markets around the world has been 27% *(Table 2-2)* over the past three years. Between 1997 and 1998 it increased to over 31%. This is of vital importance when considering the wind energy industry's potential for the future.

Market Development

Wind energy is a relatively young industry which has reached maturity extremely quickly. The level of innovation has been high, with the major manufacturers learning quickly how to refine the technology in order to make the best use of different siting situations and levels of demand for power. Most companies can now make available a range of standardised wind turbine models which compete, much as in other industries, within clearly defined research-led boundaries.

In the first period of commercialisation, during the late 1980s, wind energy's markets were concentrated in the United States and Denmark. At the beginning of the 1990s, development spread to Germany, Sweden, the Netherlands and the United Kingdom. Since then, a number of other countries have pushed themselves into a more prominent position in the market place, including India, China, Spain, Ireland and Italy.

As a new generation technology, wind energy initially found it difficult to compete on real economic terms with mature technologies applied on a large scale and backed by 40-50 years of experience and political support.

Figure 2-1: Global wind power capacity by the end of 1990 and 1998

Source: BTM Consult ApS, "World Market Update 1998", March 1999

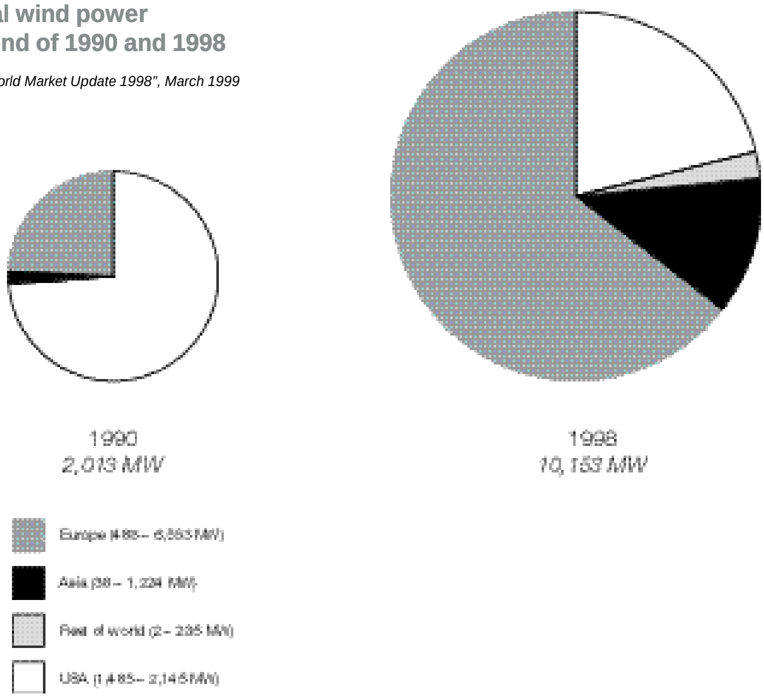


Table 2- 1: Growth in world wind energy market 1994-1998

Year	Installed new capacity – sales (MW)	Growth in annual sales (%)	Cumulative capacity by year end (MW)	Growth of cumulative capacity (%)
1993	480	108	2,758	
1994	730	52	3,488	26
1995	1,290	77	4,778	37
1996	1,292	2	6,070	27
1997	1,566	21	7,636	26
1998	2,597	66	10,153	33
Average growth in 5 years (1994 - 1998)		40.2%		29.7%

Source: BTM Consult ApS, "World Market Update 1998", March 1999

In areas with a good wind regime, wind power is now close to matching the cost of traditional electricity production. But even with cost effective turbines, it can still be difficult to compete against public utility systems with favourable financing sources, such as the ability to bill their consumers in advance of installing a power plant. A private wind turbine owner also has to finance their investment from the "real money market", where conditions often make it difficult to match a loan with the income flow from a wind turbine and a lifetime of 20 years. Economic incentives are therefore still needed to lower the risk for the investor and attract private capital to the sector.

Patterns of market penetration have therefore varied in different countries, reflecting both the means of stimulation and the maturity of the technology *(see Table 2-2)*.

The main trends in the wind energy industry in 1998 were:

- Increasing rate of expansion in new wind development – 66% increase over the rate in 1997
- A handful of big movers with an increasingly large installation rate – Germany, Denmark, Spain.
- Globalisation through establishing manufacturing capacity in new country markets, often accompanied by technology transfer to joint venture partners
- Strong focus on the development of next generation large one MW+ size wind turbines
- Renewed growth in the US market after a slow period
- Annual turnover in the industry has reached US$ 2.5 billion

Table 2-2: Growth rates in the "top ten" wind energy markets

Country	MW end 1995	MW end 1996	MW end 1997	MW end 1998	Growth rate 1997-8	3 years average rate
Germany	1,132	1,552	2,081	2,874	38.1%	36.4%
USA	1,614	1,615	1,611	2,141	32.9%	9.9%
Denmark	637	835	1,116	1,420	27.2%	30.6%
India	576	820	940	992	5.5%	19.9%
Spain	133	250	512	880	71.9%	87.7%
Netherlands	249	295	329	379	15.2%	15.0%
UK	200	273	328	338	3.0%	19.1%
China	44	79	146	200	36.7%	65.6%
Italy	33	71	103	197	91.6%	81.5%
Sweden	69	103	122	176	43.9%	36.5%
World	4,687	5,893	7,288	9,597	31.7%	27.0%

Source: BTM Consult ApS, "World Market Update 1998", March 1999

SPAIN

In the1990s, Spaniards are embracing modern wind turbines as a cheap and simple way to generate pollution-free power.

The Spanish wind energy industry has forged ahead in recent years more successfully than any other in southern Europe. Such is the level of investment that in the coming few years, the country is likely to challenge even the exceptionally fast growth rate of the market leader, Germany.

In 1993 just 52 MW of wind energy capacity was turning in the Spanish landscape, much of that concentrated in the windy district of Tarifa facing out towards Africa across the straits of Gibraltar. By the end of 1998 the total had mushroomed to 834 MW, almost half of that installed in that one year alone.

Just as important, this development is now taking place in every region of this large nation, from the jagged Atlantic coastline in the north-west to the mountains of Navarre, in the shadow of the Pyrenees, to the sun-drenched plains of Catalonia, bordering the Mediterranean.

National support

The origins of Spain's success can be found in a mixture of factors – an excellent wind regime liberally spread across a land mass over ten times as large as Denmark, a focused regional development policy and a national support scheme which is strong and straightforward.

The first piece of government legislation to provide substantial backing for renewable energy was introduced in 1994. This Royal Decree obliged all electricity companies to pay a guaranteed premium price for green power over a five year period. In outline, this environmentally-based support system operated in a similar way to the Electricity Feed law in Germany.

At the end of 1998 the government reaffirmed its commitment to renewables with a new law (Royal Decree 2818/1998) designed to bring this system into harmony with the steady opening up of European power markets to full competition. As in other countries, all companies involved in electricity production are to be privatised, and their activities in generation and distribution clearly separated.

The 1998 Decree confirmed an objective for at least 12% of the country's energy to come from renewable sources in 2010, in line with the European Union's target, and introduced new regulations for how each type of green electricity would be priced. For wind energy producers, this means that for every unit of electricity they produce they are paid a price equivalent to 88.5% of the retail sale price to consumers.

Although these prices will be updated every four years to take account of general electricity prices, the level of wind power penetration and its relative profitability, most observers believe that this legislation provides a strong basis for further wind expansion.

Provincial plans

Whilst national laws are important in Spain, a crucial impetus for wind development is coming from the bottom up, from provincial governments keen to see factories built in their area and local jobs created. The busiest provinces are Galicia, Aragon and Navarre, with Catalonia and Castilla-Leon not far behind. The incentive is simple: companies who want to develop the region's wind resource must ensure that the investment they make puts money into the local economy and sources as much of its hardware as possible from local manufacturers.

Typical of this approach is Galicia, the north-western province whose coastline juts out into the Atlantic Ocean. Starting from 1997, the regional government's grand plan is to install 5,500 turbines with a capacity of 2,800 MW by 2005. This represents about 45% of the province's power capacity. To achieve this, ten promoting companies, including both power utilities and turbine manufacturers, have been granted concessions to develop between 46 and 600 MW of capacity each within 98 specified "areas of investigation". The total investment value could reach over US$ 2.6 billion.

Galicia's aim is that at least 70% of this investment should be made within its borders, creating more than 2,000 direct and 3,000 indirect jobs. Seven major companies have already set up factories, including blade and component manufacturers and complete turbine construction plants.

The mountainous province of Navarre, which already gets 22% of its electricity from the wind, is equally ambitious. During 1999 it expects a further 110 MW to be installed, pushing the proportion to over 30%. Most of the wind farms have been built for EHN, the regional hydro-electric utility. By 2010 the province's wind capacity should have reached 650 MW, which, together with other green power sources, would make it completely self-sufficient in renewable energy.

Other regions have similar expansion plans, with a total of 8,300 MW of wind turbines planned to be constructed over the next ten years.

Domestic manufacture

Although Spain has a solid core of three totally home-based turbine manufacturers – Made, Ecotecnia and Desarrollos Eolicos – these have now been joined by as many others which use Danish technology or are jointly owned with Danish companies. These include Gamesa Eolica (using Vestas technology), NEG Micon, Bazan-Bonus and Nordex. Rules laid down by regional governments like Galicia have kept turbine imports to a minimum.

The Spanish model of development has also been different from other European countries. Most wind farms constructed have been in the 10-50 MW range, with investment coming from consortia linking power utilities, regional government, turbine manufacturers and other private investors.

Small private owners are a rarity. One reason for this is the availability of uninhabited land in zones of high wind potential. The latter reason has, on the other hand, led to some conflicts with local/regional environmental groups. This is of course a matter of discussion,and it can be solved through better planning, selection of sites taking into account environmental restrictions, strict regulations on wind park establishment, and also through granting open access to information to everybody involved, facilitating dialogue as an effective way to dealing with conflict. Unfortunately, this was not always the case, and some developments have been facing difficulties when developers tend to ignore these facts and/or opponents feel they don't have enough information. Usually, acceptance of wind parks arises after people can see there is no real environmental damage, but a contribution to environmental solutions instead, provided developments are carried out with proper care.

Financial confidence

One important feature of the Spanish market is the confident approach taken by financial institutions. Major Spanish banks are happy to lend on wind schemes, despite the fact the national law does not say how long the present system of price support will last. Keen competition means that lending rates are attractively low.

The only major technical problem faced by developers has been the poor grid infrastructure in some part of the country, necessitating the building of many kilometres of new power lines to connect up wind farms. In Galicia, for example, an investment of $130 million will be needed to reach the year 2010 target. This problem is now being solved by agreements to share the cost of grid strengthening between groups of developers who will all ultimately benefit from the improvement.

SEVEN MAJOR COMPANIES HAVE ALREADY SET UP FACTORIES, INCLUDINGBLADEAND COMPONENT MANUFACTURERS AND COM-PLETE TURBINE CONSTRUCTION PLANTS.

GERMANY

Germany is the undisputed world leader in terms of wind energy capacity. Figures for early 1999 show that more than 6,400 wind turbines were turning around the German countryside. With an installed capacity of more than 3,000 MW, they were producing more than five billion kilowatt hours of power. This is enough to satisfy over 1% of the electricity demand in a nation of 82 million people.

In fact Germany is not the ideal country for wind power. Although much of the coastline along the North Sea and Baltic is good and breezy, many inland sites have lower wind speeds than elsewhere in the continent.

Initially using mostly imported machinery from its Danish neighbour, the first large turbine were installed in the 1980s. A government-sponsored “100 MW Wind” programme in 1989 was soon extended into a 250MW programme one year later. It guaranteed investors an 8 pfennig per unit (about 4.5 US cents) subsidy, reduced to 6 pfennigs in 1991, on top of standard prices. In some areas this was backed up by regional installation grants. Alternatively, successful applicants were allowed to opt for an investment grant. In 1996 the programme was closed for new applications, after 350 MW had been contracted.

Landmark legislation

The real breakthrough came after 1991, however, when the Stromeinspeisungsgesetz (Electricity Feed Law) came into force. It was passed by the German parliament in December 1990. This landmark piece of legislation is both simple and effective. It guarantees to all renewable energy producers up to 90% of the current domestic sale price of electricity for every kilowatt hour they generate. Along with supportive regional and federal policies it has been the single most important factor behind the German boom. Semi-public banks are offering reduced rates to developers, about 0-5-1% below market rates. An amendment of the federal building code in 1996 has allowed for smoother authorisation procedures. The economic incentives and technological advancements has result in the cost of each installed kilowatt of wind power falling by over half in the last 10 years.

The last few years have seen exceptional growth. Between 1994 and 1997 an average of over 400 MW was installed each year. In 1998 alone more than 1,000 new turbines started pumping out power, with a capacity of almost 800 MW. Between 1993 and 1998, the rate of annual growth of installed wind capacity was 58%.

Industrial development

This steadily expanding market has also resulted in a number of home-based manufacturers now taking a substantial share of the wind turbine business. Competition among manufacturers as well as developers is strong, and has resulted in many technological innovations, such as variable speed, direct drive generators and megawatt turbines.

In 1998 most of the windmills constructed in Germany were made within its borders. About one third are made by Enercon, a company which has pioneered direct drive technology, avoiding the stresses and strains of a gearbox, as well as large capacity machines of 1.5 MW in output. Europe’s largest wind farm – 35 turbines with a capacity of 52 MW – was built last year near Enercon’s headquarters in the north west of Lower Saxony.

In terms of jobs, German manufacturers of complete turbines and components now directly employ more than 3,000 people. Just under a third of these were taken on during 1998. If activities such as planning, construction, operation, servicing, licensing and financing are taken into account, then almost 15,000 jobs have been created, many in the economically weak areas of northern Germany.

Regional policies

The German success story has been substantially encouraged by the policies of individual länder (regional states). The front-runner here has been Schleswig-Holstein in the north, whose long coastline has some of the best wind conditions in the country. Generous loans were made available through the non-profit making Investitionsbank, from the late 1980s to mid-1990s. The state has adopted a target for up to 20-25% of the region’s electricity to be powered by the wind in 2010 – the equivalent of 1200-1400MW. By the end of 1998 it had already achieved nearly 15%, well on the way to its goal. As importantly, the Schleswig-Holstein development plan specified suitable areas for wind energy development in order to realise the target.

There has also been development inland, in much less windy regions. The inland state of North-Rhein Westphalia, for example, has achieved more than 320 MW of wind energy capacity as a result of a mixture of special financial incentives and designating certain areas as suitable for wind farms.

Green pressure

If there are underlying reasons for the success of wind energy in Germany then one of them is certainly the strong political influence wielded by environmentalists, including the Greens, who currently share the government with the Social Democrats. Green-Social Democrat coalitions also control a number of the individual states. Environmental concern has been reflected in the strong anti-nuclear movement in

GERMANY IS THE UNDISPUTED WORLD LEADER IN TERMS OF WIND ENERGY CAPACITY.

Germany, which has effectively frozen any further atomic expansion. Greens also point to the hidden subsidies paid for nuclear and coal, dwarfing the support given to wind.

The other factor is the strong involvement by local people in wind schemes. A common pattern is for groups of residents to join together to buy a single turbine or cluster of turbines. Each person might have to invest no more than US$ 2,750, but would then be closely concerned about how “their” turbine worked. This has avoided much of the “not in my back yard” opposition seen to wind farms in some other European countries. It’s estimated that more than 100,000 Germans now have a direct investment in wind energy. More recently, as in other countries, a variety of green electricity marketing schemes have allowed thousands of others to support an additional investment.

ALMOST 15,000 JOBS HAVE BEEN CREATED, MANY IN THE ECONOMICALLY WEAK AREAS OF NORTHERN GERMANY

UNITED STATES

With the Californian boom of the mid 1980s, the United States led the way in modern large scale wind power development. A decade later it is witnessing a re-birth which promises to challenge the subsequent European dominance in manufacture and deployment of the technology.

In the year up to June 30, 1999, a record of up to 1,000 MW of wind turbines were expected to be installed across thirteen US states, bringing the country's total to some 2,500 MW. This investment is valued at more than US$1 billion. As importantly, wind energy development has now spread well beyond its original West Coast birthplace to areas as varied as Vermont and New Mexico.

The largest amount of new capacity – 247 MW – is being built in the state of Minnesota, with Iowa close behind at 240 MW. Texas, previously known only as the centre of the oil industry, ranks third with 146 MW, followed by California (117 MW), Wyoming (73 MW), Oregon (25 MW), Wisconsin (23 MW) and Colorado (16 MW). California will also host all 181 MW of so-called "repowering" projects in which new, more efficient turbines replace older wind plant.

This dramatic resurgence reflects in part the imminent expiry of the federal "Production Tax Credit" (PTC), a national support system which has provided vital backing to the US wind industry. Launched in 1992, the PTC involves a payment of 1.5 cents for every kWh of electricity produced by a wind turbine during its first ten years of operation. This has been enough to make the return from wind energy projects comparable with other fuels being used for power generation in the US.

Although the PTC was scheduled to run out in the summer of 1999, efforts are continuing on the part of the wind industry and others to ensure its revival. A number of bills being presented to the US Congress include provision for a five year extension period.

Renewables portfolio

Other factors are at work in the United States, however, which should ensure a healthy new future for wind energy whether or not the PTC is revived. One is the concept of a Renewables Portfolio Standard (RPS), a system by which an individual state decides to nominate progressive targets for an increasing percentage of its power supply to be satisfied by renewable energy. In turn, all electricity suppliers in the state are mandated by law to purchase enough "green power" to satisfy this quota. In state after state, this has resulted in wind energy projects (usually the cheapest renewable available) being commissioned.

In Iowa, for example, a law passed in 1983, but not enforced until recently, requires each of the state's investor-owned utilities to obtain 1.5% of its electricity from renewable energy. The Iowa mandate has already resulted in roughly 250 MW of new wind capacity being built. In Minnesota, a 1994 law requires the utility Northern States Power to acquire 425 MW of wind energy capacity in exchange for permission to store nuclear waste in the state. This has resulted in approximately 300 MW of new wind capacity.

The potential is much greater than this. In Texas, which is in the process of agreeing an RPS proposal, the result could be a mandate for 3% of the state's power to come from renewables by 2009. This translates into 2,000 MW, much of which is likely to be supplied by wind energy.

The other allied factor is the "restructuring" currently taking place in many of the states' electricity trading systems. As in Europe, this is resulting in the opening up of the market to new suppliers outside the traditionally monopolistic utilities. Many electricity companies are now specifically trading on the "green-ness" of their product, offering and commissioning wind power projects to satisfy an eager public demand. This has had the parallel spin-off of making consumers more directly aware of how and why wind energy is being exploited. Public enthusiasm has been particularly high at many of the new wind farms being built in states which had previously not seen large scale turbines.

New factories

Another important feature of the US revival is the boost to employment in the industry. The last year or so has seen a major wind turbine assembly plant open in Illinois, a blade making factory in North Dakota and a metal manufacturer launch a turbine tower production line in Texas.

Meanwhile, the US turbine manufacturer Enron Wind charts the impressive fall in wind energy's costs by comparing a 25 kW turbine built in 1981 with a typical 750 kW machine of today. The former would have produced 45,000 kWh annually and cost US$ 2,600 per kW of capacity. A modern turbine on a good site, on the other hand, would produce 2.5 million kWh in a year and cost just US$ 800 per kW of capacity.

DENMARK

Denmark's wind energy industry is a major commercial success story. From a standing start in the 1980s to a turnover of US$ 1 billion in 1998, its growth rate challenges those of the internet or mobile phones. Danish wind turbines dominate the global market, and the country has forged itself a position at the head of the fastest growing energy source in the world.

Over the past 15 years the Danish wind turbine industry has grown into one of the heavyweights in machinery manufacturing. Apart from the four major turbine manufacturers – Vestas, NEG Micon, Bonus and Nordex – there are a score of large component companies and dozens of smaller suppliers. From a few hundred workers in 1981 the industry now employs 15,000 people. Its turnover is also twice as large as the value of Denmark's North Sea gas production.

The last five years in particular have seen an exceptionally steady and dramatic increase in the production of Danish wind turbines. Output, mainly for export around the world, has increased sixfold to reach 1,216 MW of capacity in 1998. A further 30% growth is expected in 1999. Over half the wind turbine capacity installed globally is now of Danish origin.

Government commitments

One reason for the Danish wind industry's success is the commitment from successive governments to refuse to adopt nuclear power. More recently, the government has also decided to phase out coal completely as a fuel in new power stations. As a first step towards this, a halt has been called to all proposed coal-fired plant.

In 1981, the first Danish government energy plan envisaged 1,000 megawatts of wind energy by 2000. This total has already been exceeded. The main thrust of the latest plan, called Energy 21, is for a major reduction in carbon dioxide emissions. The target now is for a 20% cut in the 1988 level of emissions by 2005 and a halving of the figure by 2030. To achieve this, more than a third of all energy will have to come from renewable sources. Most of this will be wind power.

By 2030 wind power is expected to be supplying half of the country's electricity and a quarter of its total energy. To reach this level, a capacity in excess of 5,500 megawatts will need to be installed. 4,000 megawatts of that will be in offshore wind farms.

Offshore plans

Denmark leads the world in its development of proposals to build large wind farms of turbines in coastal waters, and then cabling the electricity back to land. The main attraction of going offshore is the enormous wind resource available. Average wind speeds can be 20 per cent higher, and the resulting energy yield up to 70 per cent greater than on land. The other incentive is the difficulty of finding enough suitable wind turbine sites on land, especially in densely populated areas.

An offshore action plan, published after extensive studies by the Danish Energy Agency and the two main electricity companies, Elsam and Elkraft, focuses initially on five specific sites around Denmark's coastal waters. Each of these will contain large wind parks of between 80 and 100 large turbines. Two pilot offshore wind farms have already been built, providing valuable feedback. The next private and utility owned offshore park of 40MW in the Copenhagen harbour is scheduled to be operating in 2000-2001

In a phased programme starting in 2001, the aim is to have at least 750 megawatts (roughly 500 turbines) of offshore wind power in place by 2005. These will mainly be developed by the two large utilities, the first time they have taken such a prominent role in Denmark's wind industry.

The first five utility wind farms, with a total capacity of 670 megawatts, are expected to involve an investment of over US$ 1,150 million. Apart from ongoing support programmes for renewable energy, no additional government funding will be made available. A Renewable Portfolio Standard and/or a green certificate scheme will finance renewable energy.

A further batch of large wind farms could bring the offshore capacity up to 2,300 megawatts by 2015. After that, a second list of sea areas will be exploited, building up to a total of 4,000 megawatts by 2030. The first large offshore scheme should be in place soon after the millennium.

Record percentage

Despite these future developments, the majority of Denmark's wind power development will continue to be on land until 2005. Figures for 1998 show that 1,500 MW of wind turbines were already up and running by the end of last year, providing 10% of the country's electricity. This is a higher proportion than any other nation in the world.

Most Danish wind turbines have been erected and operated by private owners, including specially established wind cooperatives. Over 100,000 Danish families now either own themselves or have shares in wind energy schemes. One way to make better use of the limited sites available in the country will be to replace existing small turbines with newer more powerful models.

FROM A FEW HUNDRED WORKERS IN 1981 THE INDUSTRY NOW EMPLOYS 15,000 PEOPLE.

NATIONAL PROGRAMMES AND INCENTIVES

Like other renewable sources of energy, wind power creates next to none of the pollutants associated with other methods of electricity generation, global warming and atmospheric pollution of emissions from coal or gas-fired power stations and the radioactive waste associated with nuclear plants. Coupled with its commercial development status and steadily falling costs (see Chapter 5), this has pushed wind energy into a prominent position in the range of measures being adopted by national governments to reduce their carbon emissions. Initially in Europe, but now worldwide, governments have been adopting a range of targets and measures in order to encourage a greater uptake of renewables, including wind.

Two important events in the past two years have given further encouragement to wind energy in the political arena. One was the agreement reached at the United Nations Climate Change Convention in Kyoto, Japan in 1997. This committed all the developed countries of the world to reduce their greenhouse gas emissions by agreed amounts. The second was the simultaneous decision by the European Union to a adopt a target for 12% of its total energy supply to come from renewable sources in 2010. Not only does this involve a doubling of the present proportion, but about a quarter of the renewables contribution would be expected to come from wind power.

A number of different support mechanisms and funding programmes have been launched within Europe and elsewhere to encourage market penetration by renewable energy sources, including wind. The most commonly used models are:

- Public funding for R&D programmes and demonstration projects
- Direct investment grant (% of total cost or per kW installed)
- Support for selling price of wind-powered electricity (per kWh delivered)
- Financial incentives – special loans, favourable interest rates etc
- Tax incentives – favourable depreciation, tax breaks etc

Public funding for R&D and the demonstration of innovative technologies has been the most widespread means of stimulation within Europe and the US. In the United States, the Department of Energy has backed large R&D programmes since the 1970s. Within the European Union, support for development of the next generation of MW-sized turbines under the Joule-Thermie Programme is a significant example of the EU’s contribution. Started six to seven years ago, this has resulted in up to ten MW-sized machines being available

WIND POWER CREATES NEXT TO NONE OF THE POLLUTANTS ASSOCIATED WITH OTHER METHODS OF ELECTRICITY GENERATION on the market today. Substantial national programmes have also been funded in Germany, Denmark, the UK, the Netherlands and Sweden.

Direct support for investment has been used to create markets for wind energy and develop a new manufacturing industry. Grants towards investment were used for the first time in Denmark, where the programme offered 30% initially, with a declining percentage over the next ten years. Since then the model has been used in the Netherlands, Sweden and in Germany (initially at a Federal and State level), with different rates in the individual "länder".

Support for the price of electricity delivered to the public grid has been used to stimulate markets in a number of countries. The most significant example is Germany, where the utilities are expected to pay 90% of the mix of all final consumer prices for the output from any wind project. A similar type of stimulation has been employed in Denmark, the Netherlands, Sweden , and Spain. In Italy a subsidy with a high price, available only to licensed projects, has been used, but with a limit of eight years.

In the US, the so-called "SO4" contracts gave wind turbine owners at the beginning of the 1980s a guaranteed price for electricity, increasing over ten years, and then reduced to "avoided cost level". Some 1,500 MW was installed in California supported by SO4 contracts, together with substantial tax incentives. Since 1992 a new Production Tax Credit of 1.5 UScents/kWh has been available to wind energy producers. This came to an end in July 1999, although extensive lobbying is still taking place for an extension.

The model used in the UK is also based on a subsidised selling price, but with projects supported only after a competitive bidding process.

Financial incentives usually come in the form of cheap or readily available loans or with moderate guarantee requirements. The best example of this incentive is Germany, where wind turbine owners have had access to low interest loans like those used for financing equipment in the agricultural sector. In Denmark, in the first half of the 1980s, it was possible to get loans for wind turbines linked to borrowing on real estate.

Incentives have also been offered as a "package" of support. In Denmark, the package has included a subsidy on the selling price, a direct grant towards investment and, particularly for co-operative schemes, a reduction in taxes.

Lessons for the Future

Economic incentives like those listed above cannot stand alone, however. A broader institutional framework must also be in place to secure successful development of wind energy. Elements which contribute to establishing such a framework include:

- National and international bodies working on the technical approval and certification of wind turbines.
- Careful planning for the siting of wind turbines in the landscape, with adequate consultation to ensure their acceptance by neighbouring communities.
- A competitive range of institutes and consultancies providing specialised services to the industry.

The wide range of economic incentives used to support the environmental benefits of wind energy over the past 20 years makes it difficult to draw up a clear blueprint from this experience. Programmes started more recently have gained from today's more mature technology, but longer-standing programmes have enabled an institutional framework to develop which will provide ongoing support for the technology. Nonetheless, some general conclusions can be drawn:

- No country can develop a solid industry without having access to the results of basic research and development, as well as from its own national R&D institutions.
- National R&D alone does not create markets.
- Economic incentives alone cannot achieve development in a market lacking an appropriate institutional framework for planning regulation.
- The main factor for success in the EU has been direct market stimulation by subsidising the end user, either by a grant when the turbines are installed or by subsidy per kWh during operation.
- The correct mix of economic incentives, reflecting current and future needs, has been crucial in gaining market development.
- Access for wind energy plants to the public electricity grid at a fair price has been a key issue.
- Although payment for the environmental benefits of producing electricity by wind energy is explicit in some national programmes, no formal recognition is given for this either across Europe or the United States, nor are the external costs which result from burning fossil fuels adequately recognised.

A BROADER INSTITUTIONAL FRAMEWORK MUST ALSO BE IN PLACE TO SECURE SUCCESSFUL DEVELOPMENT OF WIND ENERGY.

Is There Enough Wind?

If wind energy is to expand substantially beyond its present level around the world, then it is essential to understand clearly whether the natural resources are available to achieve these ambitious targets.

Research to date shows that the world's wind resources are huge, and distributed over almost all regions and countries. Several assessments of their magnitude have been carried out recently [2, 3].

The methodology used in such studies is to assess the square kilometres of land available with average annual wind speeds of more than 5-5.5 metres per second (m/sec) at a height of ten metres above ground level. This average speed is recognised as feasible for the exploitation of wind energy at today's generating costs. The total available resource is then reduced by 90 % or more in order to account for constraints on the use of land. This could include other human activities or infrastructure or a high population density. At the end of this process the wind resource is converted into Terawatt hours (TWh) of electricity produced per year, based on the "state of the art" performance of commercial wind turbines available on the market.

Experience from countries where wind power development is already established also shows that when more detailed assessments are carried out, more potential sites have in fact proved to be available than was expected. A good example of this has been the exploitation of less obviously windy inland sites in Germany. In other cases the local topography creates exceptionally good conditions, such as in the mountain passes of California. It is therefore likely that the total global resource will be even higher than indicated by assessments based on regional climatic observations. Finally, it should be mentioned that further improvements in the technology will extend the potential for utilising wind speeds of less than 5 m/sec.

What is clear, therefore is that the world's wind resources are unlikely ever to be a limiting factor in the utilisation of wind power for electricity production. The world's wind resources are estimated to be 53,000TWh/year, whilst the world's electricity consumption in 1998 was 14,396TWh/year, predicted to rise to 27,326TWh/year by 2020. The total available wind resource in the world today that is technically recoverable is about four times bigger than the world's entire electricity consumption in 1998.

Onshore Wind Resources in Europe

A separate analysis has been made for Europe using the figures in a study carried out by Utrecht University in 1993. This is a very conservative scenario that restricts the "exploitable resource" considerably compared with the Grubb & Meyer study used in Figure 3-1. The reason for this is Europe's high population density and large infrastructure elements (roads, airports, railways etc.).

In Table 3.1, the total technical wind energy potential is shown for each country alongside the amount that it would have left over after a notional 20% "penetration limit" had been set on the ability of a national grid network to accommodate large amounts of wind power (see " Electricity Grid Limitations" below). One reason for doing such calculations in Europe is that all the national grids are interconnected, enabling the export of electricity from one country to another.

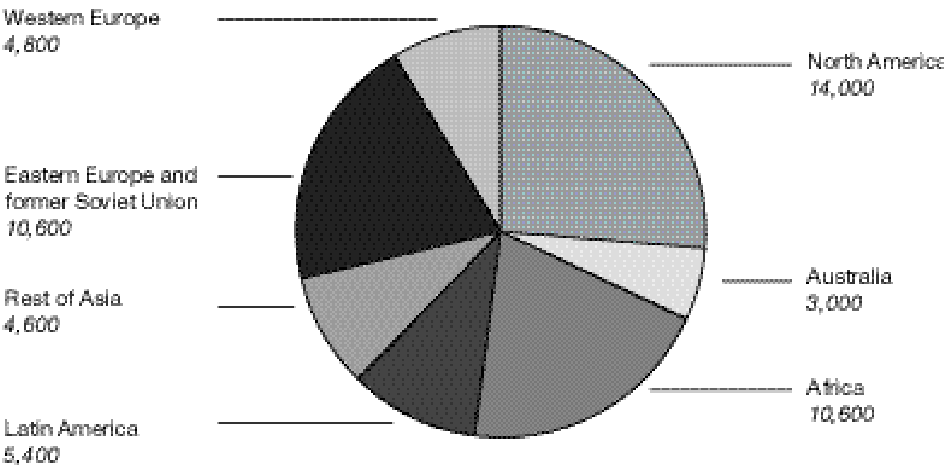


Figure 3-1 The world's wind resources World total = 53,000 TWh

Source: Wind resources from Michael Grubb and Niels Meyer, 1994 [2]
Note: The total potential (land with an average wind speed above 5.1 m/s at 10 m height) has been reduced by 90 % to take into account other uses, population density etc. The assessment does not include Greenland, the Antarctic or offshore areas. Figures not available for OECD Pacific Region (Australia, NZ and Japan) and Middle East.

Table 3-1: Technical potential for onshore wind power in EU-15 plus Norway

Country	Total electricity consumption, (TWh/year[1])	Technical wind potential TWh/year, (GW capacity)	Up to 20% of consumption from wind,(TWh/year)	Surplus wind ,over 20% consumption (TWh/year)
Austria	60	3 (1.5)	3	–
Belgium	82	5 (2.5)	5	–
Denmark	31	10 (4.5)	6.2	3.8
Finland	66	7 (3.5)	7	–
France	491	85 (42.5)	85	–
Germany	534	24 (12)	24	–
Great Britain	379	114 (57)	75.8	38.2
Greece	41	44 (22)	8.2	(?) [2]
Ireland	17	44 (22)	3.4	40.6
Italy	207	69 (34.5)	41.4	27.6
Luxembourg	1	0	–	–
Holland	89	7 (3.5)	7	–
Portugal	32	15 (7.5)	6.4	8.6
Spain	178	86 (43)	35.6	50.4
Sweden	176	41 (20.5)	35.2	22.8
Norway	116	76 (38)	23.2	
Total	2,500	630 (315)	366.4	244.8

Source: BTM Consult; technical wind potential from Wijk and Coelingh, 1993 [3]

1 Electricity consumption is based on OECD/IEA figures for 1989, extended by 3% per annum to 1995. The latest IEA "World Energy Outlook" (1998) records a total consumption for OECD-Europe in 1995 of 2,678 TWh.
2 Greece has an excess potential, but with resources scattered over many islands is unlikely to be an exporter for some time.

The Utrecht University study was carried out in 1993 where the average "new" wind turbine was 250-300kW. It is obvious that with the recent upscaling to an average 700kW size, the rotors of the turbines are at a height of 50 metres instead of 30 meters, resulting in a higher annual yield. The study is therefore conservative in the context of today's "state of the art" technology.

Another important observation is that when more detailed assessment are carried out for a specific region, it tends to find much higher potentials. For example detailed studies in Germany by the Ministry of Economic Affairs (Bundesministerium für Wirtschaft Energieesparung und Erneuerbare Energien, Dokumentation No. 361 December 1994) has shown that the onshore wind potential is 124 TWh (64,000MW) a factor five times higher higher than the 24TWh given in Table 3.2.

The figures in Table 3.1 indicate that there is an exploitable potential for onshore wind power in Europe of more than 600 TWh/year. Some EU countries can also produce much more electricity from the wind than they could use internally. This presents a challenge to the developing cross-border European power market, and the extent to which it encourages trading in "green electricity".

Offshore Wind Resources in Europe

There is also an enormous wind resource to be found in the seas around the coastline of Europe, to be added to the total European potential. Several European countries, led by Denmark, are already in the planning stage for their first large scale offshore wind farms. The ambitious programme proposed by the Danish government, based on several years' feasibility studies, is described in a Chapter 2. The European wind turbine manufacturing industry is also focussing its current R&D effort on producing new designs specially adapted for the emerging offshore market. This is expected to take off in Northern Europe from the year 2001 onwards.

A study by consultants Garrad Hassan and Germanischer Lloyd, carried out under the EC's Joule programme in 1993-5, estimates an offshore wind potential in the EU of 3,028 TWh. Even though Norway and Sweden were not included in the study, this figure far exceeds the total electricity consumption within the Union's 15 current members in1997. The majority of the European offshore resource has been identified in the UK, Denmark and France.

The methodology used in this study uses a geographical data base called GIS (Geographical Information System) developed by Garrad Hassan, and the tools and models used

Table 3-2 : Offshore wind resources in Europe (electricity production in TWh/year)

Water depth	Up to 10 km offshore	Up to 20 km offshore	Up to 30 km offshore
10 m	551	587	596
20 m	1,121	1,402	1,523
30 m	1,597	2,192	2,463
40 m	1,852	2,615	3,028

Source: "Study of Offshore Wind Energy in the EC", Garrad Hassan & Germanischer Lloyd, 1995

for the analysis are described in the report[15]. In order to quantify the resource a reference wind turbine of 6 MW capacity and 100 m diameter rotor was used, with the spacing between turbines set at one kilometre.

This study assumes that the wind resource can be used out to a water depth of 40 m and up to 30 km from land. For the purposes of this report, BTM Consult have taken a very conservative approach of the potential shown in Table 3-2 in order to come up with a likely "exploitable resource" which can be recognised as available for development within the next two to three decades and with the technology likely to be in use during that period.

Reductions to the figures in the offshore resources study have been made using the following criteria. Because of the expense involved, particularly in foundation work, all water depths over 20 m have been excluded. Sites less than 10 km from the shore have been reduced by 90% to be sensitive to visual concerns. The resource within the range 10-20 km from the shore has been reduced by half in order to allow for potential visual restrictions and adequate spacing between wind farms, whilst the 20-30 km resource has also been reduced by 50% on the assumption that the expense of lengthy power cable connections will deter smaller developers.

Even taking all these reductions into account, the final figure for European offshore wind potential amounts to 313.6 TWh, about 10 % of the gross potential identified in the offshore study. This is still equal to half the potential on land in Europe.

The combined figure for both land and sea, taking into account the most feasible offshore sites, leaves Europe with a potential resource of some 940 TWh – enough to meet 21% of anticipated electricity demand by 2020.

Most importantly, since only 10% of the gross potential has been accounted for, improved technology and cheaper foundation techniques are likely to make it easy to extend the offshore contribution by a significant amount.

Table 3-3 : Projections of future electricity demand by region

Region of the world Growth 1995-2020	1995 (TWh)	1998 (TWh)	2010 (TWh)	2020 (TWh)	Annual growth (%)
OECD - Europe	2,678	2,875	3,836	4,492	1.67
OECD - North America	4,110	4,362	5,508	6,363	1.54
OECD - Pacific	1,190	1,236	1,613	1,865	1.56
Latin America	772	871	1,409	2,073	2.68
East Asia	608	708	1,294	2,030	3.33
South Asia	485	568	1,070	1,657	3.42
China	1,036	1,234	2,497	3,857	3.72
Middle East	327	357	513	839	2.57
Transition Economies (Former Soviet Union + Eastern Europe)	1,631	1,777	2,491	3,298	2.02
Africa	367	408	622	851	2.32
World Total	13,204	14,396	20,852	27,326	2.07

Source: "World Energy Outlook 1998", IEA

Future Demand for Electricity

Future demand for electricity is assessed from time to time by international organisations, including the World Energy Council and the International Energy Agency. In the "World Energy Outlook", published by the IEA in 1996, two scenarios were presented for the development of the world's energy up to 2010. These were described as the Capacity Constraints Case and the Energy Savings Case. The figures for projected demand are shown in Figure 3-2.

More recently, the IEA has produced its "World Energy Outlook 1998". In this new study there is only one scenario for projected future electricity demand, described as "Business as Usual". The horizon has also been extended to 2020. Future demand according to this projection is shown in Figure 3-3.

By choosing a "Business as Usual" scenario, this reflects the cautiousness of the IEA over the world community's efforts to reduce electricity consumption. In Table 3-3, this expected future demand for electricity is distributed by regions, following the IEA's geographical definitions (see Appendix 1).

For the world as a whole, it can be seen that electricity consumption is expected to almost double by 2020. In the

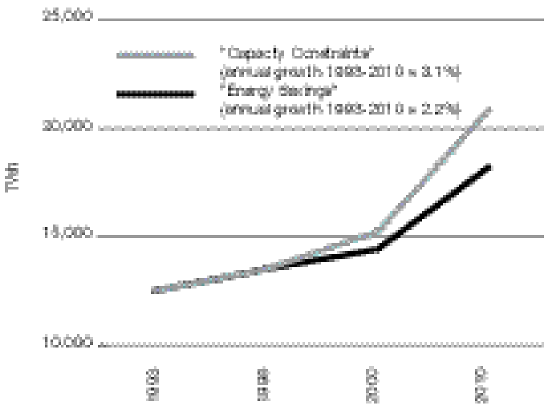


Figure 3-2 : Projections for future electricity demand (1996)

Source: "World Energy Outlook 1996", IEA

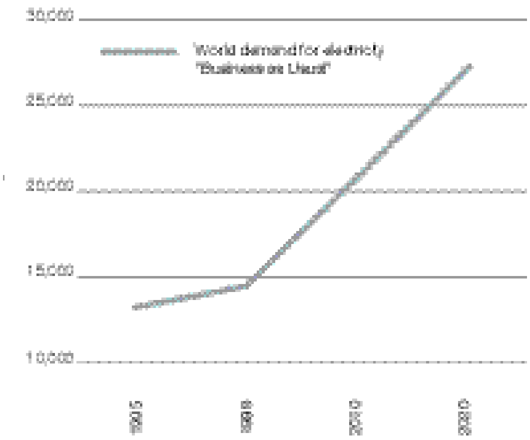


Figure 3-3 : Projections for future electricity demand (1998)

Source: "World Energy Outlook 1998", IEA

Table 3-4 : Available wind resources and future electricity demand

Region of the world	Electricity demand by 2020 (TWh/year)	20 % of 2020 demand (TWh/year)	Wind resource (TWh/year)	Factor of the resource exceeding 20% penetration by 2020
OECD - Europe	4,492	898.4	Land: 630 Offshore: 313	1.05
OECD - N.America	6,363	1,272.6	14,000	11
OECD - Pacific	1,865	373	3,600	8
Latin America	2,073	414.6	5,400	13
East Asia	2,030	406		
South Asia	1,657	331.4	4,600	3
China	3,857	771.4		
Middle East	839	167.4	n.a.	
Transition Economies	3,298	659.6	10,600	16
Africa	851	170.2	10,600	63
World Total	27,326	5,465.2	49,743	9.1

new economies of Asia and Latin America, demand is expected to triple.

It is therefore clear that a contribution from wind power to meet 10% of global consumption within 20 years will call for approximately 2,500 - 3,000 TWh/year – more than the total electricity consumption in Europe at present.

However, this 3,000TWh represents 20% of 1998 global electricity consumption, highlighting the significant additional benefits if the Business as Usual scenario does not occur.

Electricity grid limitations

The quantity of wind-powered electricity which can be readily integrated into a country or region's electricity grid depends mainly on the system's ability to respond to fluctuations in wind energy supply. Any assessment must therefore include data about the extent of output from other power station suppliers, their ability to regulate their supply, and the consumption pattern in the system, particularly variations in the load over a daily and annual timescale.

Numerous assessments involving modern European grids have shown that no technical problems will occur by running wind capacity together with the grid system up to a penetration level of 20%. In demonstration projects on the Greek islands and on Cape Verde in the Atlantic Ocean very high penetration has been successfully demonstrated for several years using wind turbines within small diesel-powered grids.

Studies in Denmark [10] has shown that a penetration level of up to 30-40 % is possible if the future electricity system is prepared in advance by adopting a flexible design. In the latest Danish Energy Plan (9), the goal is to cover 50% of Danish electricity consumption from wind energy by 2030. This includes the use of interconnectors and exchange of electricity with neighbouring countries, among them Norway and Sweden, both of which have large capacities of hydro power.

The assumption adopted here is that a 20% limit is an acceptable figure to be taken into account in further studies of the potential penetration of wind power into the world's grid networks.

Table 3.4 shows how the world's wind resources are able to easily satisfy the technical issues of attaining a level of 20% of electricity penetration by 2020.

Outline of the 10% Scenario

The initial sections of this report have described the current status of wind energy development around the world, the environmental impetus behind its expansion, the global wind resource region by region and the expected increase in electricity demand which will have to be satisfied. These elements are now brought together to demonstrate that it is feasible for 10% of that worldwide demand for electricity to be supplied by wind power. The summary results of this exercise can be seen in Table 4-1. More detailed figures are given in the Appendices.

This feasibility study takes off from the figures for cumulative wind energy at the end of 1998. The total installed capacity around the world was then 10,153 MW, with new installations during 1998 reaching 2,597 MW (here rounded to 2,600 MW). The growth rate of new annual installation during the period 1998 to 2003 is estimated to be 20% per annum, ending up with some 33,400 MW on line by the end of 2003.

The development pattern needed to achieve the 10% target calls for the highest growth rates (30%) during the period 2004 to 2010. From 2010 onwards yearly growth rates will decline, although the continued growth of wind power will clearly take place at a new high level of annual installation.

By the end of 2020, an installed capacity of 1,200 GW (1.2 million MW) will have been achieved, with an annual production capable of matching 10% of the world's demand for electricity, as projected by the IEA.

Beyond 2020, development continues with an annual installation rate of 150,000 MW. Market penetration is expected to follow a typical S-curve, with a "saturation" point reached some 30-40 years into the next century, when a global level of roughly 3,000 GW of wind energy will be maintained. Over time, an increasing share of new capacity is used for replacement of old wind power plant. This assumes a 20 year average lifetime for a wind turbine, requiring replacement of 5% of capacity each year.

Growth rates for wind energy are based on a mixture of historical figures (1990-1998) and information obtained from leading companies in the wind turbine market. The exploitable wind potential worldwide and the level of electricity consumption in different regions of the world have also been assessed. Future cost reductions in wind technology are based on expectations of "learning rates" and take off from today's level, which is approximately US$ 1,050 per kW of installed capacity resulting in a price per kWh of 5.0 US cents.

The growth rate beyond 2003 will be supported by new capacity from the emerging offshore wind power market, scheduled to take off in 2001, mainly in Northern Europe. Demand from this market is expected to make an important contribution to the growth of wind power capacity in Europe. There are as yet no offshore resource assessments available from other parts of the world.

Assumptions and Parameters

The choice of parameters used in this study has been based on historical experience from both the wind energy industry and from other technological developments in the energy field. The main assumptions are presented below:

Annual growth rates

Growth rates of 20-30% per annum are very high for an industry manufacturing heavy equipment. However, the wind energy industry has experienced far higher growth rates in the initial phase of its industrialisation. Between 1993 and 1998, the average annual growth figure was 40%. The "bottleneck" for maintaining a growth rate of 30% per year. from 2004 to 2010 is in fact likely to be the industry's ability to meet the demand by increasing its manufacturing capacity. After 2010 the annual growth rate of new capacity slows down to 20% and later, in 2016, to 10%. The growth in manufacturing capacity levels out at a figure of 150,000 MW annually.

Based on the ongoing expansion of the wind energy industry, it is quite capable of meeting a growth in demand of some 30% a year for at least five years ahead. By the end of 1999 manufacturing capacity is expected to reach a level of 5-6,000 MW/year, with adequate venture capital available for further development. An important factor is the likely opening up of offshore development from 2001 onwards in Europe, a market segment which will add further volume to the generally high level of expansion on land. Nonetheless, a clear message from the industry is that it would like to see a stable political framework established for wind power development in emerging markets around the world before it enters local manufacturing through joint ventures. A fuller assessment of the industry's growth potential is given in Appendix 6.

Progress ratios[1]

The general conclusion from industrial "learning curve theories" is that costs decrease by some 20% each time the number of units produced doubles. A 20% decline is equivalent to a progress ratio of 0.80. Studies of the past development of the wind power industry[6] show that progress through "R&D efforts and by learning" resulting in a 15-20% price reduction –equivalent to "progress ratios" of 0.85 to 0.80 respectively. In the calculation of cost reductions in this report, experience has been related to "numbers of units – i.e. turbines and not Megawatt capacity. The increase in average unit size is therefore also taken into account.

The progress ratio assumed in this study starts at 0.85 up until 2013. After that it is reduced to 0.88 and 0.90 in 2013

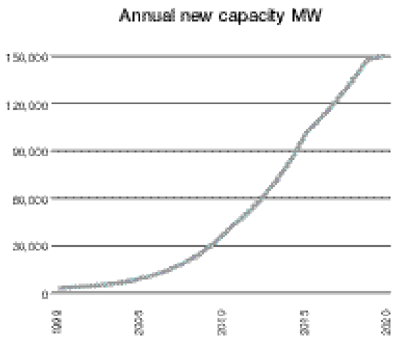
1 Technological development is characterised by improvements in efficiency, design, manufacturing, installation and use of a certain product. This trend is called "progress by learning" or "learning curve effect". Studies of past developments this century show that its is generally true that each time experienced doubles (i.e. cumulative production) cost declines between 20 and 30% net of inflation. (Johnson & Scholes, 1984 P.344 in Reference[6])

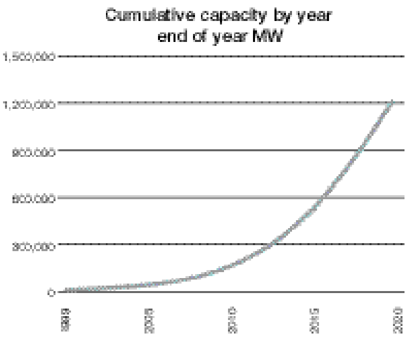
Table 4-1 : 10% wind-powered electricity worldwide by 2020

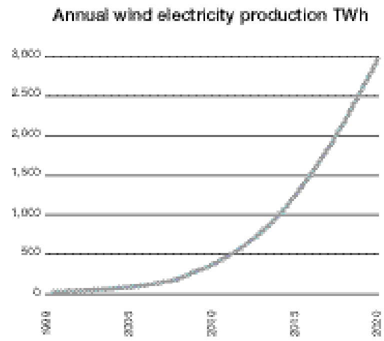
Year	Average annual growth rate	Annual new capacity (MW)	Cumulative capacity by end of year (MW)	Annual wind electricity production (TWh)	World electricity demand (TWh)	Wind power penetration of world electricity (%)
1999		3,120	13,273	29.1	14,919	0.19
2000		3,744	17,017	37.3	15,381	0.24
2001	20%	4,493	21,510	47.1	15,858	0.30
2002		5,391	26,901	58.9	16,350	0.36
2003		6,470	33,371	73.1	16,857	0.43
2004		8,411	41,781	91.5	17,379	0.53
2005		10,934	52,715	115.4	17,918	0.64
2006		14,214	66,929	146.6	18,474	0.79
2007	30%	18,478	85,407	187	19,046	0.98
2008		24,021	109,428	268.4	19,937	1.37
2009		31,228	140,656	345	20,245	1.70
2010		40,596	181,252	444.6	20,873	2.13
2011		48,715	229,967	564.1	21,445	2.63
2012		58,458	288,425	707.4	22,033	3.21
2013	20%	70,150	358,575	879.5	22,636	3.89
2014		84,180	442,755	1,086	23,256	4.67
2015		101,016	537,059	1,333.8	23,894	5.58
2016		111,117	654,888	1,606.3	24,548	6.54
2017	10%	122,229	777,117	1,906.1	25,221	7.56
2018		134,452	911,569	2,235.9	25,912	8.63
2019		147,897	1,059,466	2,598.7	26,622	9.76
2020		**150,000**	**1,209,466**	**2,966.6**	**27,351**	**10.85**
2030		150,000	2,545,232	6,242.9	33,178	18.82
2040		150,000	3,017,017	7,928.7	38,508	20,60

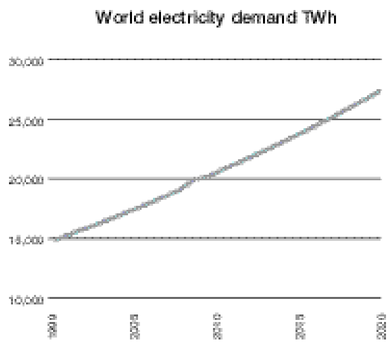
BTM Consult ApS - May 1999

Note: Figures for global electricity demand from IEA, 1998. Projections beyond 2020 have been extended by growth rates of 2 % and 1.5 % p.a. for the two following decades respectively.









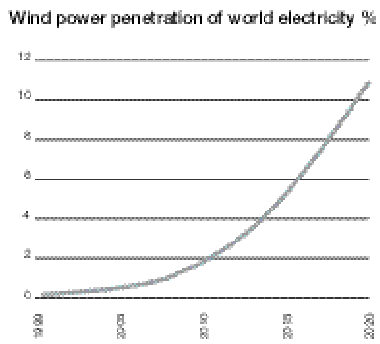


Table 4-2: Average size of wind turbine installed each year (kW)

Year	Denmark	Germany	Spain	Sweden	UK	US
1992	215	185	125	212	361	223
1993	248	254	200	247	320	149
1994	364	371	320	412	469	336
1995	493	473	297	448	534	327
1996	531	530	420	459	562	511
1997	560	623	422	550	514	707
1998	687	783	504	590	615	723

Source: BTM Consult ApS, "World Market Update 1998", March 1999

and 2018 respectively. Beyond 2024, when development is approaching its saturation level, it goes down to 0.95, and later 1.0.

The reason for this graduated assumption, particularly in the first seven years, is that the manufacturing industry has not, so far, gained the full benefit from series production, especially due to the rapid upscaling of products. Neither has the full potential of future design optimisations been utilised. Even so, the cost of wind turbine generators has still fallen significantly during the 1990s, and the wind industry is recognised as having entered the "commercialisation phase", as understood in learning curve theories.

Future growth of wind turbine size

Table 4-2 shows the rapid growth of wind turbine size in the commercial market over the past seven years. From this it can be seen that in the leading markets – Germany, Denmark, Spain and the United States – the average size of wind turbine being installed has grown by a factor of three to four.

In the 10% scenario, the average size of wind turbine is expected to grow over the next decade from today's figure of 700 kW to 1.5 MW. During 1998, roughly 16% of the capacity installed consisted of turbines of 1 MW size or larger. By the middle of the first decade of the next century this development will be pushed even harder by the emerging offshore sector. Wind turbines for that market are expected to be in the size range 2-3 MW. On land, the most commonly used turbine, at least until 2010, is expected to be in the size range 700-1,000 kW, with a rotor of 50 metres diameter. Most importantly, the development of larger sizes reduces the number of turbines needed for a given capacity and decreases the progress ratio.

Increases in capacity factor

The capacity factors of wind turbines have already increased from 0.20 to 0.23-0.25 today. This is the result of both better initial design and better siting. Most recently, the major contribution to improved capacity factors has been the increased hub height above ground of the larger turbines. The production of wind turbines with relatively large rotors (for inland sites) has also contributed. From the point of view of the utility electricity network, a high capacity factor is welcomed because it means more power into the grid at a given point. It is also worth noting that improving the capacity factor of wind turbines presents no technical problems, it is simply a matter of improved grid integration, modelling and cost.

Comparisons with Other Technologies

If wind energy is to achieve the level of market penetration anticipated in this feasibility study, how does that compare with the record of other power sources?

The most commonly used power plants in the world's electricity supply are "large scale technologies" such as thermal power stations fired with coal, gas or oil, nuclear reactors and large scale hydro-electric plants. Both nuclear power stations and large scale hydro are technologies which have been mainly developed since the middle of this century. They have now reached a penetration of 16% and 19% respectively in the world's power supply.

- Starting from 1,000 MW in 1960, nuclear power plants accounted for 343,000 MW by the end of 1997.
- Starting from 45,000 MW in 1950, hydro power plants accounted for 714,602 MW by the end of 1996.

The history of these two technologies proves that it is possible to achieve such levels of penetration with a new technology over a period of 40-50 years. Wind energy is today a commercial industry that is capable of becoming a mainstream electricity power choice. The time horizon of the 10% target and beyond is consistent with the historical development of nuclear power and large scale hydro

It is difficult, nonetheless, to compare these technologies with the likely penetration pattern for wind energy. The main difference between wind power and thermal plant is that wind power is a small scale technology, with a maximum unit size today of 1.65 MW, but the modularity of wind power therefore makes it ideal for all sizes of installations, from a single unit to huge wind farms. On the supply side this gives a greater potential for cost reduction, with serial production of units. It also makes wind energy suitable for many different types of electricity infrastructure, from isolated loads fed by diesel power to huge national and transnational grids.

Seen from that point of view it is quite feasible that wind energy can penetrate to a level of 10%. The amount of installed capacity would then in fact be equivalent to that of hydro power – even though on paper it appears some 50% higher. This is because of wind power's lower capacity factor. In this study we have taken a range from 0.25 to 0.30. The capacity factor for hydro power is typically 0.60.

Two other factors are important in the development of a new technology. One is the market "push" from publicly funded R&D, the other is the market "pull" achieved by a wide range of incentives directed either towards investors in generation technology or the end user of electricity. The latter stimulation is often politically driven.

The relative progress of new power technologies has been assessed in a recent report, "Global Energy Perspectives", produced by the Austrian institute IIASA and the World Energy Council in 1998[5]. The report gives the following examples, all from the United States:

Photovoltaics – from 1981 to 1992, a progress ratio rate of 20% (0.80)
Wind turbines – from 1982 to 1987, a progress ratio of 20% (0.80)
Gas turbines – progress ratio of 20% for the first 1,000 MW installed, then 10% from 1963 to 1980, when 90,000 MW was installed.

Penetration levels based on the above assumptions have been used in Table 4-1.

Breakdown of the 10% Scenario by Region

The general guideline followed in the 10 % Scenario has been to distribute the 1,200 GW to be installed by 2020 in proportion to the consumption of electricity in the different regions of the world. The OECD countries, however, are expected to take the lead in implementation, enabling them to grow faster and ending up with a surplus in relation to their global share of electricity consumption. An adjustment has therefore been made for Europe and for North America, particularly the USA.

Another consideration has been the quality of wind resources in terms of regional share of "high average wind speed regimes". It is obvious that areas with extremely high annual wind speeds will be more interested in developing wind power than large areas with moderate wind speeds, even if the absolute resources are huge in the latter.

A third subject, which has not been assessed in detail for this report, is how the windy regions of the world are situated in relation to where the consumption takes place. If the main areas generating wind electricity in a country are concentrated far from the populated areas and industrial centres, it might either result in restrictions on the utilisation of wind power or require a major investment in transmission lines.

The expected geographical distribution of 1,200 GW of wind power by end of the year 2020 is shown in Table 4-3.

Table 4-3 : 10% wind power in 2020 - regional breakdown

Region (IEA definition)	Share of 1,200 GW of wind energy in 2020 (MW)	Share of 1,200 GW of wind energy in 2020 (%)	Total electricity demand in 2020 (TWh)
OECD - Europe	220,000	18.2	4,492
OECD - N. America	300,000	24.2	6,363
USA 1)	250,000		
Canada 1)	50,000		
OECD - Pacific	90,000	7.4	1,865
Latin America	90,000	7.4	2,073
East Asia	80,000	6.6	2,030
South Asia	60,000	5.0	1,657
China	180,000	14.8	3,857
Middle East	25,000	2.1	839
Transition Economies	140,000	11.6	3,298
Africa	25,000	2.1	851
World	1,210,000	100	27,325

Sources: Global consumption by 2020 - IEA, 1998; Identified resources - Grubb/Meyer and Wiljk/Coelingh; Offshore resources in Europe - Garrad Hassan & Germanischer Lloyd, 1995. The 10% scenario - BTM Consult ApS, May 1999

Investment Value

This feasibility study shows investment on a yearly basis, starting with about US $3 billion in 1999 and increasing to a peak of US$ 78 billion in 2020. The total investment (at 1999 prices) required to reach the level of 1,200 GW of wind power worldwide in 2020 is estimated at US$ 721 billion. This is a very large figure, although it should be borne in mind that it is cumulative over the whole 20-year period. It must also be placed in a global energy context, where the annual investment in the power sector has been some US$ 170-200 billion each year during the 1990s [5]

These figures for wind power investments appear high but they account for only a fraction of the total global power sector investments.. By 2020 it might represent a more substantial fraction, but by then, it should be remembered, wind energy development will be heading towards a coverage of 20 % of electricity demand – equal to that of hydro power today.

Table 5-1 shows the cumulative global investment needed to achieve 10 % penetration by the year 2020. Investment costs are based on the progress assumptions used in the spreadsheets in Appendix 2, with the average price level in 1999 taken as US$ 975 per kW of installed wind energy. The progress ratio starts at 0.85 and is later reduced to 0.88 and 0.90 over the first two decades of the century. By 2020 the investment cost has fallen to US$ 556/kW, a substantial reduction of 43 % compared to today.

Analysing how this investment would be spread around the regions of the world is not just a matter of dividing up the capacity in accordance with the regional distribution in Table 4-3. This is because development will not start at the same time in all regions. Experience from the leading wind power nations has shown that even with commercial technology available, it still takes some time for large scale development to take off. The institutional framework facilitating the development must be in place, and it is desirable to get at least some local manufacturing in place before major investments are made.

In order to make this analysis, Table 5-2 shows the average investment cost over different periods of time in the first two decades of the 21st century. This in turn allows us to allocate

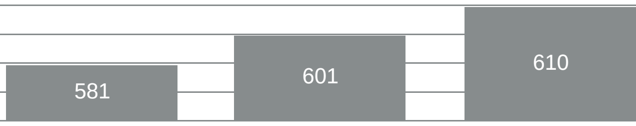
Table 5.1 Investment, installation and employment of 10% of the world's electricity by 2020

Year	Annual Installation (MW/year)	Cost (US$/kW)	Investment (US$ billion/year)	Cumulative Investment (US$ billion)	Employment (Job-year)
1998	2.600	1.000	2.600	2.600	57.200
1999	3.120	975	3.041	5.641	66.910
2000	3.744	948	3.551	9.193	78.126
2001	4.493	921	4.139	13.332	91.062
2002	5.391	897	4.834	18.166	106.352
2003	6.470	871	5.636	23.802	123.991
2004	8.411	852	7.164	30.966	157.612
2005	10.934	830	9.072	40.038	199.582
2006	14.214	810	11.508	51.546	253.170
2007	18.478	787	14.540	66.086	319.882
2008	24.021	762	18.298	84.384	402.551
2009	31.228	734	22.935	107.319	504.580
2010	40.596	705	28.640	135.959	630.084
2011	48.715	677	33.000	168.959	725.992
2012	58.458	650	38.010	206.969	836.217
2013	70.150	629	44.155	251.124	971.418
2014	84.180	609	51.285	302.409	1.128.265
2015	101.016	590	59.556	361.965	1.310.228
2016	111.117	572	63.549	425.514	1.398.088
2017	122.229	556	67.939	493.454	1.494.667
2018	134.452	544	73.090	566.543	1.607.970
2019	147.897	532	78.711	645.254	1.731.649
2020	150.000	522	78.339	723.594	1.723.461
Total				723.594	

Note: It is assumed that the employment is directly proportional to the investment, thus employment decreases along with the "progress" according to progress ratios and cost reductions - see appendix 2. Beyond 2020, annual investment would continue at a level of $US 83 billion a year. The cost would only decrease very little as "progress gains" would by then have been made.

Table 5-2 : Average investment per kW of wind power, 1999 to 2020

Period	Average investment (US$/kW)
1999 to 2004	897
2005 to 2010	752
2011 to 2015	623
2015 to 2020	559



Source: BTM Consult ApS, "10 % Scenario", May 1999

the regional investment, taking into account when development in individual regions is likely to take off (Table 5-3).

Cost Reductions

The cost per unit (kWh) of wind electricity has already reduced dramatically as manufacturing and other costs have fallen. An evaluation of wind turbines installed in Denmark carried out by the RISØ National Research Laboratory in 1995 (6) found that costs had dropped from 16.9 UScents/kWh in 1981 to 6.15 UScents/kWh in 1995, a decrease of two thirds. The reasons given included improved design of turbines and better siting.

Since these calculation were done, the 500 kW size turbines then just being introduced into the commercial market have been optimised and further upscaled to 600 kW and 750 kW versions. The result is that unit prices are in some cases now as low as 4.6 UScents/kWh. In the latest round of the UK's renewables bidding system (1998), for example, the average price per kWh of wind power was 4.7 UScents/kWh.

Based on the above, this study has taken the following reference figures for "state of the art" wind turbines in 1998:

- Investment cost: 1,000 $US/kW
- Unit price for electricity: 4.7 UScents/kWh
- The range of wind power costs today is 4-7cents/kWh

Future Costs

The Danish study cited above uses "learning curve theories" to predict future wind energy cost reductions. With a strong element of R&D backing, the results project figures of 4 UScents/kWh by 2005 and 3.2 UScents/kWh by 2020. These assume a cumulative capacity of just 180,000 MW by 2020, however, six times smaller than the 10% scenario.

Similar results were produced by a United States Department of Energy study in 1993, with figures of 3.6 UScents/kWh in 2010 and 3.1 UScents/kWh in 2020. Significantly, this assessment assumed that the average size of wind turbine would not pass 500 kW until 2010, whilst in fact it is already at the 700 kW level.

The general impression from reviewing these studies – accomplished just three to five years ago – is that both the industry and the market suggests a higher rate of declining costs, at least in the short term, than expected few years ago.

Based on these studies, and others from Swedish and Finnish analysts (An improved market penetration model for Wind Energy technology Forecasting Prof. PD Lund, Helsinki University of Technology, Advanced Energy Systems. Paper presented on EWEA special topic conference, Helsinki, September 1995), the following parameters have been used for the calculations of future costs:

1. The average size of turbine on the commercial market will grow from 700 kW today to 800 kW by 2002, 1,200 kW by 2004 and later to 1,500 kW, depending on the share of offshore developments after the turn of the century.

2. Progress ratios declining from 0.85 in steps to 0.90 by 2018 and beyond 2023 to 0.95. This takes into account improved cost effectiveness and improved design gained from R&D as well as benefits from better logistics and "economies of scale".

3. Improvement in the average capacity factor from today's 0.23 to 0.28 after 2007.

This feasibility study therefore indicates a cost reduction in wind electricity from today's 4.7 UScents/kWh[3] to a level below 3 UScents/kWh by 2013 – only 14 years ahead. By 2020, the figure will have fallen to just 2.5 UScents per unit of electricity produced. The year by year cost reductions can be seen in Appendix 2.

Comparison with other generation technologies

How do the costs of wind energy compare with other generating technologies already in widespread use? The following table is extracted from the EWEA's "Wind Energy: The Facts", Volume 5, based on a study by the EU/UNIPEDE in 1995. The price bands in the cost of power column reflect varying interest rates. The figures for wind energy are derived from this assessment.

3 To avoid confusion, this 4.7 cents/kWh cost is separate from the 4.7cent/kWh 'state of the art' price given above. The 4.7 cents/kWh cost is derived from extrapolation of the 1995 RISØ study into 1997. It takes into account the "progress" gained from the 500kW class to the 660-705kW class, representing a reduction of some 20-25% compared to the 500kW class in 1995. It might be a little higher or lower, but it is representative for an average wind roughness class of 1.5 (In the US Class 3-4)

Table 5-3 : Distribution of investment by region up to 2020

Region	Take-off year for large scale development	Total installation by 2020 (MW)	Cumulative investment by 2020 ($US billion)
OECD - Europe		220,000	134.2
OECD - N. America		300,000	183.0
(USA)	(250,000) (152.5)		
OECD - Pacific	2001	90,000	54.9
Latin America	2002	90,000	54.9
East Asia	2005	80,000	48.1
South Asia	2002	60,000	36.1
China	1999	180,000	109.8
Middle East	2005	25,000	15.0
Transition Economies	2005	140,000	84.1
Africa	2000	25,000	15.0
World		1,210,000	720.1[2]

Source: BTM Consult ApS, "10 % Scenario", May 1999

2 The figures for each region are rounded, taking into account the time of take-off. Therefore the sum of the regions makes up some 2% more than the figures in the bottom row, derived from appendix 1.

It should be borne in mind that UNIPEDE is a utility organisation which tends to be more optimistic, for example, about the future costs of nuclear power plants. It is obvious, nonetheless, that wind energy in certain cases is already competitive today, and even without fully taking its environmental benefits into account.

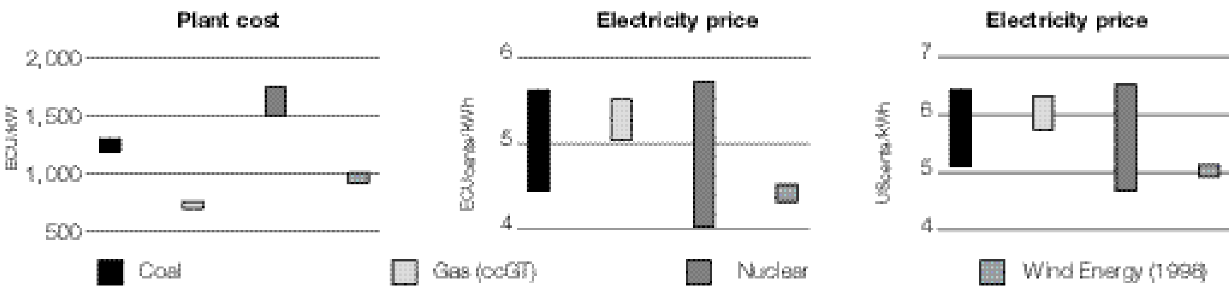
One other factor should be taken into account in these comparisons. The relatively low capacity factor of wind power means that to produce a given quantity of electricity it is necessary to install 2-2.5 times more generating capacity than with fossil fuel plants. This tends to make wind energy more expensive in the initial phase of the life cycle. On the other hand there is no fuel cost during the lifetime of a wind power generating plant. Wind energy costs are also expected to drop significantly over the next two decades, as cumulative experience grows. The three "thermal generation technologies" mentioned here are unlikely to get significantly cheaper than they are today.

Employment Potential

The employment effect of the 10% wind energy scenario is a crucial factor to weigh alongside its other costs and benefits. High unemployment rates continue to be a major drain on the economies of nearly every country in the world. Any technology which demands a substantial level of both skilled and unskilled labour is therefore of considerable economic importance, and likely to feature strongly in any political decision-making over different energy options.

Looking two decades ahead, it may not still be reasonable to assume that employment will continue to be a determining parameter. However, if the opposite situation should occur – a shortage of labour – then it is equally important to know how

Table 5-4: Prices for different generating technologies.



Source of fossil fuel and nuclear statistics: EU/UNIPEDE, 1995 much employment different activities require. There are good reasons, therefore, for knowing the employment figures involved in a long term technological development such as this.

Several assessments of the employment effects of wind power have been carried out in Germany, Denmark and Holland. The most comprehensive study to date is by the Danish Wind Turbine Manufacturers Association in 1996 (13). This work was also the main source for Volume 3 of the European Wind Energy Association publication “Wind Energy: The Facts”.

The methodology used by the DWTMA is to break down the manufacturing activities involved in the wind turbine industry into its different sectors – metal work, electronics etc. – and then add together the individual employment contributions. The results cover three areas – the direct and indirect employment from wind turbine manufacture, the direct and indirect employment effects of installing wind turbines, and the global employment effects of the Danish industry’s exports business.

One good reason for using the Danish figures is that the country’s wind turbine industry has been the most successful during the 1990s on the supply side, with a world market share consistently close to 50 %. It is reasonable to assume, however, that the methodology used by the DWTMA will be valid for the other main turbine manufacturing nations – Germany, Spain and the United States.

For the purposes of this study, the latest available Danish figures (1998) for employment are used. These show that 17 man-years are created for every MW of wind energy manufactured and 5 job-years for the installation of every MW. With the average price per kW of installed wind power at US$ 1,000 in 1998, these employment figures can then be related to monetary value, showing that 22 job-years (17+5) are created by every US$ 1 million in sales.

In order to allow for greater efficiency in design, manufacture and installation – resulting in a reduction in employment – it has been chosen to let the labour consumption follow the total value of wind energy installation, a decreasing value over time. These indicative reductions in the level of employment over the period of the 10% study are shown in Table 5-5 (see Appendix 4).

The results of the employment assessment for the entire implementation of the 10 % scenario are shown in Table 5-6. These are directly based on the assumptions above and the actual new installation of wind power expected in the years 2005, 2010, 2015 and 2020. In the intermediate period, from 2005 to 2020, it is assumed that some regions start their large scale development of wind energy later than OECD countries already on track for a major deployment.

It is also important to emphasize that a prerequisite for the employment figures allocated by regions in Table 5-6 is that the whole manufacturing process, including the upstream production and supply of the technology, is provided within the region itself. Given that this is unlikely to be a totally realistic outcome, with the present world trading situation, the expected local “value added” and derived employment to be obtained from the 10% scenario is assessed separately in the tables listing the key figures by region (see Appendix 1).

In the first part of Table 5-6, the total installation quota of wind energy is divided by regions into periods of five years. For individual regions, the figures can only represent a rough estimate, however, since a detailed assessment of the penetration pattern has not been possible within the limits of this study. Nonetheless, the sum of each five years makes up the total annual figure in accordance with the 10 % scenario (see Table 4-2)

The annual installation figures in MW are turned into employment figures in Table 5-6b below:

These “core figures” will have to be corrected region by region, taking into account such issues as the actual price of labour, manufacturing efficiency (related to the above), and the rate of import of materials or components for manufacturing the regional share of global installation.

Table 5-6a : Distribution of annual installed capacity by region at five year intervals

Region	2005 (MW)	2010 (MW)	2015 (MW)	2020 (MW)
OECD - Europe	4,500	8,000	18,000	22,000
OECD - N. America	3,500	10,000	25,000	28,000
(USA) (3,000) (8,500) (21,000) (24,000)				
OECD - Pacific	300	3,200	8,000	15,000
Latin America	400	3,500	8,000	15,000
East ASIA	200	2,500	6,000	10,000
South ASIA	600	2,200	5,000	8,000
China	800	6,000	15,000	25,000
Middle East	100	600	2,200	3,500
Transition Economies	300	4,000	12,000	20,000
Africa	200	600	2,200	3,500
Annual installation MW/year (Table 4-2)	10,934	40,596	101,313	150,000
Man-years/MW (Table 5-5)	18.3	15.5	13.0	12.3

The annual installation figures in MW are turned into employment figures in Table 5-6b below:

Table 5-6b :Distribution of employment by region at five year intervals

Region	Man-years x 1,000			
	2005	2010	2015	2020
OECD - EUROPE	82.3	124.0	234.0	252.7
OECD - N. America	64.0	155.0	325.0	321.7
åΔåΔåΔåΔ(USA) [[[(54.9) åΔåΔ(131.7)[[[(273.0) åΔ(275.9)				
OECD - Pacific	5.5	49.6	104.0	172.3
Latin America	7.3	54.3	104.0	172.3
East ASIA	3.7	38.7	78.0	114.9
South ASIA	11.0	34.1	65.0	91.9
China	14.6	93.0	195.0	287.2
Middle East	1.8	9.3	28.6	40.2
Transition Economies	5.5	62.0	156.0	229.8
AFRICA	3.7	9.3	28.6	40.3
Total Employment Man-years/year	200,000	629,200	1,317,000	1,722.600
Annual installation MW/year (Table 4-2)	10,900	40,600	101,300	150,000
Man-years/MW (Table 5-5)	18.3	15.5	13.0	12.3

Global Carbon Dioxide Reductions

A reduction in the levels of carbon dioxide being emitted into the world's atmosphere is the most important environmental benefit from wind power generation. Carbon dioxide is the major gas largely responsible for exacerbating the greenhouse effect, leading to the disastrous consequences of global climate change.

At the same time, modern wind technology has an extremely good energy balance. The CO2 emissions related to the manufacture, installation and servicing over the life-cycle of a wind turbine are "paid back" after the first three to six months of operation.

The benefit to be obtained from carbon dioxide reductions in a country's energy mix is dependant on which other generation method wind power is substituting for. Calculations by the World Energy Council (referred to in the EWEA report [8]) make the following assumptions:

On the assumption that coal and gas will still account for the majority of electricity generation in 20 years' time – with a continued trend for gas to take over from coal – it make sense to use a figure of 600 tonnes per GWh as an average value for the carbon dioxide reduction to be obtained from wind generation.

This assumption is further justified by the fact that 50 % of the cumulative wind generation capacity two decades ahead, according to our scenario, will be installed in the OECD regions (North America, Europe and the OECD-Pacific). The trend in these countries is for a significant shift from coal to gas. Such development will start a little later in other regions, but in some, the specific CO2 reduction will be much higher due to the widespread use of inefficient coal burning power stations.

Taking account of these assumptions, covering 10 % of the global demand for electricity with wind power will reduce carbon dioxide emissions by the following amounts:

- Between 1999 and 2010 –
  A cumulative reduction of 1,120 million tonnes CO2
- Between 2011 and 2020 –
  A cumulative reduction of 9,530 million tonnes CO2
- Annual reduction by 2010 – 444,600 GWh x 600 tonnes = 266.7 million tonnes CO2/year
- Annual reduction by 2020 – 2,966,600 GWh x 600 tonnes
= 1,780 million tonnes CO2/year
- By 2040 wind power will contribute an annual reduction of 4,757 million tonnes CO2

The Effect of Improved Efficiency

As already explained, the improving efficiency of wind technology is expected to follow a pattern from today's average capacity factor of 23 % to 25 % a few years ahead, and ending up with figures of 28 % and 30 % in 2007 and 2030 respectively. Expressed in terms of the benefit to an electricity utility, this is a shift from 2,000 "full-load hours" per year to 2,500-2,600 hours/year. Future offshore installations are expected to perform even better – in the range of 3,000-3,500 hours/year. It should also be noted that wind turbines in particularly windy sites on land in Denmark, the US and the UK have already demonstrated capacity factors of 30 % and above.

These improvements in the technology and the growth rates seen in the 10% scenario will make an important contribution to the level of CO2-free electricity.

Appendix 5 shows the carbon dioxide reductions from the feasibility study calculated year by year from 1999 to 2020.

Value of Carbon Dioxide Reductions

Many studies have been carried out to determine the abatement cost of CO2 reductions. The general conclusion is that energy saving is often the cheapest option. When it comes to generating plant, this will depend on the local structure of the electricity system and which fuel is being replaced. Studies in Denmark have shown that wind power replacing coal produced electricity represents one of the lowest CO2-abatement costs of all options available. Around the world there will be many places where wind power will result in no abatement cost at all when substituting for fossil fuels.

A common misunderstanding in this area is that new wind power is often compared with fossil fuel generation built up to 30 years ago, and with its capital cost depreciated to zero. In an electricity market under the competitive pressure of a deregulated market, such plant may well deliver power at prices only a little over the variable cost. That situation will not last forever. As soon as demand growth calls for new capacity, wind power will be in a far better competitive position.

If the future improvements on cost effectiveness calculated for this study are taken into account, then the abatement cost of substituting wind energy for fossil fuel generated electricity is likely to be near zero.

External Costs

The "external costs" to society derived from burning fossil fuels or from nuclear generation are not included in most electricity prices. These costs have both a local and a global component, the latter mainly related to the eventual consequences of climate change. There is a lot of uncertainty, however, about the magnitude of such costs, and they are difficult to identify and quantify. A well-known European study[7], known as the "Extern E" project, has assessed these costs for fossil fuels within a wide range, consisting of three levels:

Table 6-1: CO2 emissions from fossil fuelled electricity generation

Coal (various technologies)	751-962 tonnes per GWh
Oil	726 tonnes per GWh
Gas	428 tonnes per GWh
Average	600 tonnes per GWh

Source: WEC statistics cited in "Wind Energy - The Facts", Volume 4, 1998, EWEA/European Commission

Low:	3.8 ECU/tonne CO2 equal to 4.3 US$/tonne
Medium:	18-46 ECU/tonne CO2 equal to 20.7- 52.9 US$/tonne
High:	139 ECU/tonne CO2 equal to 160 US$/tonne

By contrast, very low values are attached to the externalities related to wind power.

Taking a conservative approach to the “Extern E” study, uses a value for the external costs of carbon dioxide emissions in the range of 10-20 US$/tonne CO2. The assessment above concludes that wind power reduced emissions of CO2 by an average value of 0.6 kilos/kWh. The resulting external costs avoided for every kWh produced by wind energy will therefore be in the range of 0.6-1.2 UScents/kWh.

The effect of this calculation is that even the most basic and conservative environmental benefits of wind power should either result in a reduction in its price of 0.6-1.2 UScents/kWh or that figure should be added to the costs for fossil generated electricity. Many analysts believe that in the not too distant future these external costs will to some extent be quantified and reflected in the market prices for electricity.

It is also interesting to note that this figure for external costs is significantly lower than the future reduction potential of wind electricity costs, as already discussed in Chapter 5.

This feasibility study has shown clearly that wind power is in the vanguard of the new renewable energy industries. Yet like other renewables it is being held back in many markets of the world by a lack of political impetus. In order to achieve a minimum level of 10% of the world's electricity from wind power by 2020, three essential actions are required. These are:

1. Establishing firm targets for wind power around the world
2. Removing the inherent barriers and subsidies which penalise renewables
3. Implementing mechanisms to secure and accelerate the new market for wind energy

These actions are detailed in the following policy recommendations:

1. Establishing Targets

In order to reduce greenhouse gas emissions, protect the climate and to ensure transition to a sustainable energy economy, the establishment of clear renewable energy targets is essential. These targets would then be used as a guide, and drive technology transfer programmes, as policy rules for International financial Institutions and Multilateral Development Banks, and as an incentive to the private sector to invest in wind power and other renewable energy sources.

- Set national, regional and international(see page 39*) targets and annual timetables, particularly for the years 2005, 2010 and 2020, which will deliver a minimum of 10% of the world's electricity from wind power by 2020 as well as substantial support for other renewable energy sources. For the electricity sector such targets should be set as a percentage of consumed electricity.
- Ensure that the "Clean Development Mechanism" and "Joint Implementation" under the Kyoto Protocol are "clean and green" by only authorizing and crediting projects that support wind power and other renewable energy (except large dams) and the most technically and economically energy efficient and environmentally sound technologies (it therefore excludes nuclear power).
- Make technology transfer programmes consistent with climate protection by ensuring that the multi-lateral development bank and government lending arrangements promote the development of wind power technology worldwide.

2. Removing Inherent Electricity Sector Barriers

Planning and access legislation in the electricity sector has been built around the existence of large power plants with a constant supply. This represents an outdated institutional barrier to renewable energy which must be removed if wind power is to thrive. Specific requirements are for:

- s Streamlined and uniform planning and permitting systems for both project planning and access to electricity grids.
- The costs of grid infrastructure development and reinforcement to be carried by the grid management authority rather than individual renewable projects.
- Fair and transparent pricing for electricity throughout a network, with recognition and remuneration for the benefits of "embedded" generation.
- The removal of discriminatory transmission and access tariffs.

3. Halting Fossil Fuel Subsidies

The effect of vast subsidies in the energy sector is that taxpayers pay to have their health damaged, their environment poisoned and their climate destroyed. Importantly, subsidies shut out new players from the established markets. Subsidies also create severe market distortions, and prevent the total real cost of different energy sources being used as the basis for new capacity procurement. Required actions are to:

- Halt all direct and indirect subsidies to fossil fuels and nuclear energy.
- Incorporate a "polluter pays" pricing system into the electricity market by switching the charge for the environmental, social and health impacts from the taxpayer to the costs of the offending project.

4. Promoting Renewable Energy

The most important elements in attracting investment to "green power" are that the renewable energy market is clearly defined, stable and provides sufficient returns to investors. Various policy mechanisms have been shown to successfully deliver wind power and other renewables capacity. The options available include:

a) Defining the market for private investors by clearly setting the purchase price or the demand volume for renewable energy. This could include setting minimum prices, quotas or a system of portfolio standards.
b) Establishing mechanisms for support and investment in new technology, industrial development and resource mapping.
c) Establishing priority procurement for renewable energy capacity and priority dispatch for produced energy.
d) Setting fiscal and taxation incentives to accelerate ßmarket development.

*International Targets

The Kyoto Protocol and the UN Framework Convention on Climate Change mandates directly or indirectly action to support wind power and other renewable energy systems in several main ways :

Support for renewables: Kyoto Protocol Article 2 (a) (iv) requires that each Party included in Annex I undertakes promotion, research, development and increased use of new and renewable forms of energy.

Reduce market barriers Kyoto Protocol Article 2(v) requires for the Annex I Parties "Progressive reduction or phasing out of market imperfections, fiscal incentives, tax and duty exemptions and subsidies in all greenhouse gas emitting sectors that run counter to the objective of the Convention and apply market instruments";

Early action for Annex I Parties. Kyoto Protocol Article 3 paragraph 2 states that each Party included in Annex I shall, by 2005, have made demonstrable progress in achieving its commitments under this Protocol. Apart from having begun to reduce emissions, an element of demonstrable progress needs to be increasing the share of renewable energy.

Technology Transfer

The UN FCCC Article 4.1 requires that all Parties take steps that are consistent with mitigation of climate change and paragraph 5 of Article 4 requires that the Annex I Parties take steps to transfer environmentally sound technology to developing countries. Renewable and wind energy systems in particular are ideal candidates for large-scale technology transfer. At present this provision of the UN FCCC has not been implemented to any significant degree.

This is taken further in the Kyoto Protocol where Paragraph (c) of Article 10 requires that all Parties "cooperate in the promotion of effective modalities for the development, application and diffusion of, and take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies, know-how, practices and processes pertinent to climate change, in particular to developing countries, including the formulation of policies and programmes for the effective transfer of environmentally sound technologies that are publicly owned or in the public domain and the creation of an enabling environment for the private sector, to promote and enhance the transfer of, and access to, environmentally sound technologies".

Technology transfer within the CDM

Whilst the CDM does not specifically refer to renewable energy Article 12, paragraph 5 does require that emission reductions only be certified where projects produce "Real, measurable, and long-term benefits related to the mitigation of climate change" and "Reductions in emissions that are additional to any that would occur in the absence of the certified project activity".

Where renewable projects are genuinely additional to what would otherwise have occurred then they should qualify for emission credits under the CDM. Given the requirement for "long-term benefits" the CDM should in fact be restricted to only those technologies that can guarantee such benefits.

The rules, modalities and criteria to be agreed for the CDM therefore need to ensure that there are strict technology, baseline and additionality standards that give priority to renewable energy projects and high energy efficiency projects.

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APPENDIX 1

10% wind energy by 2020 – contributions by region

Contributions and benefits by region

In this Appendix, the contribution to the "10 % scenario" for each region of the world is described, together with the benefits to be gained from the development, expressed in a few key figures. The figures for each region has been derived from Tables 4-3, 5-6b, 5-1 and the Table in Appendix 5.

This distribution by region has necessitated some corrections. These corrections are not assessed in detail but represent a "best estimate" based on specific information from the individual regions. The following are the main changes:

Employment In the Asian regions labour input has been increased by 20 %. Import quotas have not been considered, although they will be significant in the initial phase. However, the added volume in these countries becomes huge at the end of the period (2015-2020), by which time an almost 100% technology transfer has taken place. In the "Transition Economies" the increase is 10 %.

CO2 reduction In the Asian regions the carbon dioxide reduction has been increased by 30 % due to the generally low efficiency of coal generation efficiency in these areas. In the Transition Economies the increase is 20 %.

Investments In regions with a poor infrastructure (grid and high voltage lines) the regional investment has been increased by some 10 %. The basis for that judgement is experience of the grid systems in Europe and other OECD regions.

Regions	Installed wind capacity by 2020 (MW)	Annual electricity production from wind power (TWh/year)	Penetration of Wind Power by 2020 (% of electricity consumption)
OECD - EUROPE	220,000	539.6	12
OECD - N. AMERICA	300,000	735.8	11.6
USA	250,000	613.2	11.3
OECD - PACIFIC	90,000	218.5	11.7
LATIN AMERICA	90,000	218.5	10.5
EAST ASIA	80,000	196.2	9.7
SOUTH ASIA	60,000	147.2	8.9
P.R CHINA	180,000	441.5	11.4
MIDDLE EAST	25,000	61,5	7.3
TRANSITION Economies	140,000	343.2	10.4
AFRICA	25,000	61.3	7.2
Total	**1,210,000**	**2,963.3**	**10.85**

BTM-Consult May 1999

APPENDIX 2 – Tables for Market Development, Cost Reduction, Electricity consumption growth (IEA), 1999 to 2040

Total figures for Investment, Carbon Dioxide reduction and Employment – deviates from the total figures in other tables, due to regional corrections included (see outer right column). The figures for USA are included in those for OECD-N. America.

Definitions of Regions in accordance with IEA classification

OECD-Europe: The EU-15 plus Czech Republic, Hungary, Iceland, Norway, Switzerland and Turkey
OECD N. America: USA and Canada
OECD Pacific: Japan, Australia and New Zealand
Transition Economies: Albania, Bulgaria, Romania, Slovak Republic, Former Jugoslavia and Former Soviet Union and Poland
East Asia: Brunei, Dem. Republic of Korea, Indonesia, Malaysia, Philippines, Singapore, Rep. of Korea, Chinese Taipei, Thailand, Vietnam and some smaller countries, including the Polynesian Islands
South Asia: India, Pakistan, Bangladesh Sri Lanka and Nepal
Latin America: All South American countries and islands in the Caribbean
Africa: Most African countries in the North and the South
Middle East: Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates and Yemen

Cumulative Investment (US $ billion)	Annual reduction of CO2 by 2020 (Million tonnes /year)	Employment in the region by 2020 (Man-year /year)	Comments/Corrections:
134.2	323.7	270,600	*Incl. 70,000 MW offshore*
183.0	441.5	325,000	
152.5	367.9	273,000	
54.9	131.1	184,000	
60.4	131.1	184,500	*Correction: Investment: +10%*
52.9	153.0	147,600	*Corrections : Employment: +20% Investment : +10% CO2 reduction: +30%*
39.7	114.8	118,100	
120.8	344.4	369,000	
15.0	36.4	43,100	
92.5	247.2	270,600	*Corrections : Employment: +10% CO2 reduction: +20%*
16.5	36.7	51,720	*Corrections : Employment: +20% Investment : +10%*
769.9	**1,959.9**	**1,964,220**	

APPENDIX 2 – Tables for Market Development, Cost Reduction, Electricity consumption growth (IEA), 1999 to 2040

Table 1 Market penetration

Growth ratio	Year	Cumulative (MW)	Annual (MW)	Annual avg. WTG (MW)	Cumulative no. of units	Capacity factor (%)	Production (TWh)	Progress ratio
20%	1998	10,153	2,600		38,761	25	22.2	0.85
	1999	13,273	3,120	0.7	43,218	25	29.1	
	2000	17,017	3,744	0.7	48,567	25	37.3	
	2001	21,510	4,493	0.7	54,985	25	47.1	
	2002	26,901	5,391	0.8	61,724	25	58.9	
	2003	33,371	6,470	0.8	69,811	25	73.1	
30%	2004	41,781	8,411	1.2	76,820	25	91.5	
	2005	52,715	10,934	1.2	85,931	25	115.4	
	2006	66,929	14,214	1.5	95,407	25	146.6	
	2007	85,407	18,478	1.5	107,726	25	187.0	
	2008	109,428	24,021	1.5	123,740	28	268.4	
	2009	140,656	31,228	1.5	144,559	28	345.0	
	2010	181,252	40,596	1.5	171,623	28	444.6	
20%	2011	229,967	48,715	1.5	204,099	28	564.1	
	2012	288,425	58,458	1.5	243,071	28	707.4	
	2013	358,575	70,150	1.5	289,838	28	879.5	0.88
	2014	442,755	84,180	1.5	345,958	28	1,086.0	
	2015	543,771	101,016	1.5	413,302	28	1,333.8	
10%	2016	654,888	111,117	1.5	487,380	28	1,606.3	
	2017	777,117	122,229	1.5	568,866	28	1,906.1	
	2018	911,569	134,452	1.5	658,501	28	2,235.9	0.90
	2019	1,059,466	147,897	1.5	757,099	28	2,598.7	
0%	2020	1,209,466	150,000	1.5	857,099	28	2,966.6	
	2021	1,354,973	150,000	1.5	957,017	28	3,323.5	
	2022	1,499,582	150,000	1.5	1,056,930	28	3,678.2	
	2023	1,643,112	150,000	1.5	1,156,837	28	4,030.2	
	2024	1,784,702	150,000	1.5	1,256,728	28	4,377.5	0.95
	2025	1,923,768	150,000	1.5	1,356,600	28	4,718.6	
	2026	2,059,554	150,000	1.5	1,456,451	28	5,051.7	
	2027	2,191,077	150,000	1.5	1,556,280	28	5,374.3	
	2028	2,317,055	150,000	1.5	1,656,086	28	5,683.3	
	2029	2,435,828	150,000	1.5	1,755,870	28	5,974.6	
	2030	2,545,232	150,000	1.5	1,855,633	28	6,242.9	
	2031	2,646,516	150,000	1.5	1,955,395	28	6,491.4	
	2032	2,738,058	150,000	2.0	2,030,154	30	7,195.6	1.00
	2033	2,817,908	150,000	2.0	2,104,912	30	7,405.5	
	2034	2,883,729	150,000	2.0	2,179,669	30	7,578.4	
	2035	2,932,713	150,000	2.0	2,254,424	30	7,707.2	
	2036	2,971,595	150,000	2.0	2,329,196	30	7,809.4	
	2037	2,999,366	150,000	2.0	2,403,981	30	7,882.3	
	2038	3,014,914	150,000	2.0	2,478,777	30	7,923.2	
	2039	3,017,017	150,000	2.0	2,553,582	30	7,928.7	
	2040	3,017,017	150,000	2.0	2,628,407	30	7,928.7	

APPENDIX 2 – Tables for Market Development, Cost Reduction, Electricity consumption growth (IEA), 1999 to 2040

Table 2 Cost reduction according to penetration, in Table 1

Progress Ratio	Year	Cumulative (MW)	Cumulative no. of units	Electricity (cent/kWh)	Electricity (DKK/kWh)	Capacity (US$/kW)	Capacity (DKK/kW)
85%	1998	10,153	38,761	4.71	0.325	1,000	kr 6,900
	1999	13,273	43,218	4.59	0.317	975	kr 6,726
	2000	17,017	48,567	4.47	0.308	948	kr 6,545
	2001	21,510	54,985	4.34	0.299	921	kr 6,357
	2002	26,901	61,724	4.22	0.291	897	kr 6,187
	2003	33,371	69,811	4.10	0.283	871	kr 6,011
	2004	41,781	76,820	4.01	0.277	852	kr 5,878
	2005	52,715	85,931	3.91	0.270	830	kr 5,725
	2006	66,929	95,407	3.81	0.263	810	kr 5,586
	2007	85,407	107,726	3.71	0.256	787	kr 5,430
	2008	109,428	123,740	3.59	0.248	762	kr 5,256
	2009	140,656	144,559	3.46	0.239	734	kr 5,068
	2010	181,252	171,623	3.32	0.229	705	kr 4,868
	2011	229,967	204,099	3.19	0.220	677	kr 4,674
	2012	288,425	243,071	3.06	0.211	650	kr 4,486
88%	2013	358,575	289,838	2.96	0.205	629	kr 4,343
	2014	442,755	345,958	2.87	0.198	609	kr 4,204
	2015	543,771	413,302	2.78	0.192	590	kr 4,068
	2016	654,888	487,380	2.69	0.186	572	kr 3,946
	2017	777,117	568,866	2.62	0.181	556	kr 3,835
90%	2018	911,569	658,501	2.56	0.177	544	kr 3,751
	2019	1,059,466	757,099	2.51	0.173	532	kr 3,672
	2020	1,209,466	857,099	2.46	0.170	522	kr 3,604
	2021	1,354,973	957,017	2.42	0.167	514	kr 3,544
	2022	1,499,582	1,056,930	2.38	0.164	506	kr 3,491
	2023	1,643,112	1,156,837	2.35	0.162	499	kr 3,443
95%	2024	1,784,702	1,256,728	2.34	0.161	496	kr 3,422
	2025	1,923,768	1,356,600	2.32	0.160	493	kr 3,403
	2026	2,059,554	1,456,451	2.31	0.159	491	kr 3,385
	2027	2,191,077	1,556,280	2.30	0.159	488	kr 3,368
	2028	2,317,055	1,656,086	2.29	0.158	486	kr 3,353
	2029	2,435,828	1,755,870	2.28	0.157	484	kr 3,338
	2030	2,545,232	1,855,633	2.27	0.157	482	kr 3,325
	2031	2,646,516	1,955,395	2.26	0.156	480	kr 3,312
100%	2032	2,738,058	2,030,154	2.26	0.156	480	kr 3,312
	2033	2,817,908	2,104,912	2.26	0.156	480	kr 3,312
	2034	2,883,729	2,179,669	2.26	0.156	480	kr 3,312
	2035	2,932,713	2,254,424	2.26	0.156	480	kr 3,312
	2036	2,971,595	2,329,196	2.26	0.156	480	kr 3,312
	2037	2,999,366	2,403,981	2.26	0.156	480	kr 3,312
	2038	3,014,914	2,478,777	2.26	0.156	480	kr 3,312
	2039	3,017,017	2,553,582	2.26	0.156	480	kr 3,312
	2040	3,017,017	2,628,407	2.26	0.156	480	kr 3,312

*Cost (DKK/kWh) = a *(X/X0)^-b*

US$ 1 = DKK 6.90

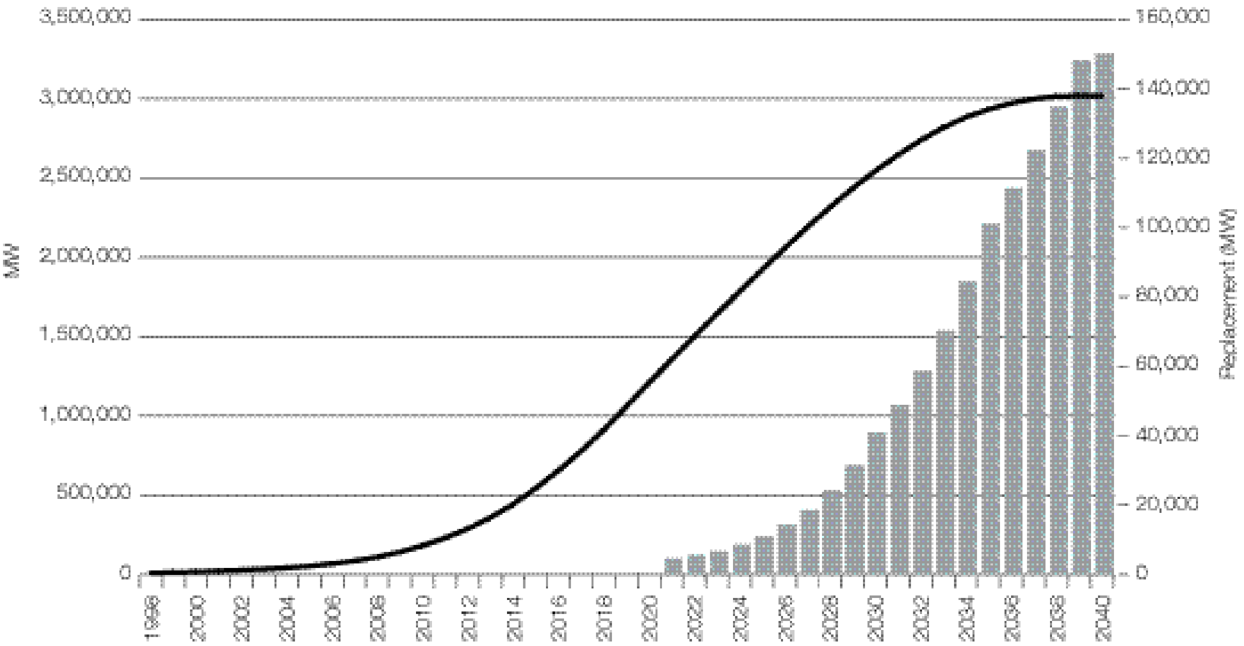
Table 3 Projected electricity consumption - IEA, 1998

Consumption growth rate	IEA-global (TWh)	Year	Wind (TWh)	Penetration (%)
3.10%	14,470	1998	22.2	0.15
	14,919	1999	29.1	0.19
	15,381	2000	37.3	0.24
	15,858	2001	47.1	0.30
	16,350	2002	58.9	0.36
	16,857	2003	73.1	0.43
	17,379	2004	91.5	0.53
	17,918	2005	115.4	0.64
	18,474	2006	146.6	0.79
	19,046	2007	187.0	0.98
	19,637	2008	268.4	1.37
	20,245	2009	345.0	1.70
	20,873	2010	444.6	2.13
2.74%	21,445	2011	564.1	2.63
	22,033	2012	707.4	3.21
	22,636	2013	879.5	3.89
	23,256	2014	1,086.0	4.67
	23,894	2015	1,333.8	5.58
	24,548	2016	1,606.3	6.54
	25,221	2017	1,906.1	7.56
	25,912	2018	2,235.9	8.63
	26,622	2019	2,598.7	9.76
	27,351	2020	2,966.6	10.85
2.00%	27,898	2021	3,323.5	11.91
	28,456	2022	3,678.2	12.93
	29,026	2023	4,030.2	13.89
	29,606	2024	4,377.5	14.79
	30,198	2025	4,718.6	15.63
	30,802	2026	5,051.7	16.40
	31,418	2027	5,374.3	17.11
	32,047	2028	5,683.3	17.73
	32,688	2029	5,974.6	18.28
1.50%	33,178	2030	6,242.9	18.82
	33,676	2031	6,491.4	19.28
	34,181	2032	7,195.6	21.05
	34,693	2033	7,405.5	21.35
	35,214	2034	7,578.4	21.52
	35,742	2035	7,707.2	21.56
	36,278	2036	7,809.4	21.53
	36,822	2037	7,882.3	21.41
	37,375	2038	7,923.2	21.20
	37,935	2039	7,928.7	20.90
	38,504	2040	7,928.7	20.59

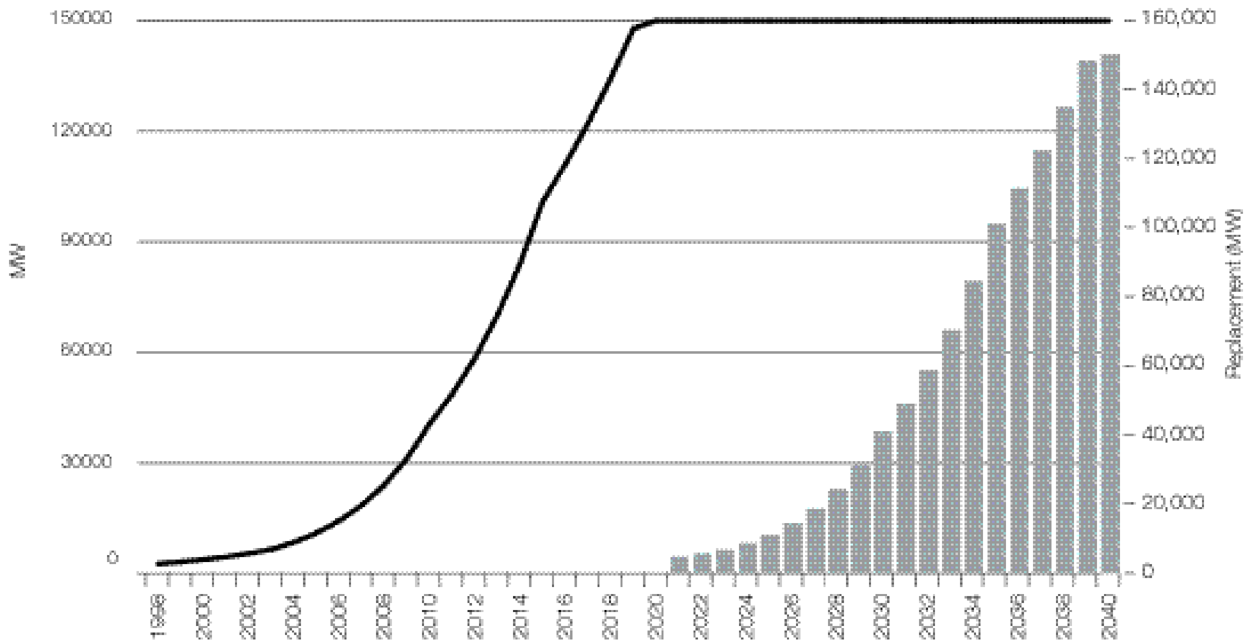
Figures beyond the year 2020. estimated by BTM Consult ApS

APPENDIX 3 – Graphs showing penetration/annual added capacity and replacement (1999-2040)

Penetration Curve (MW)

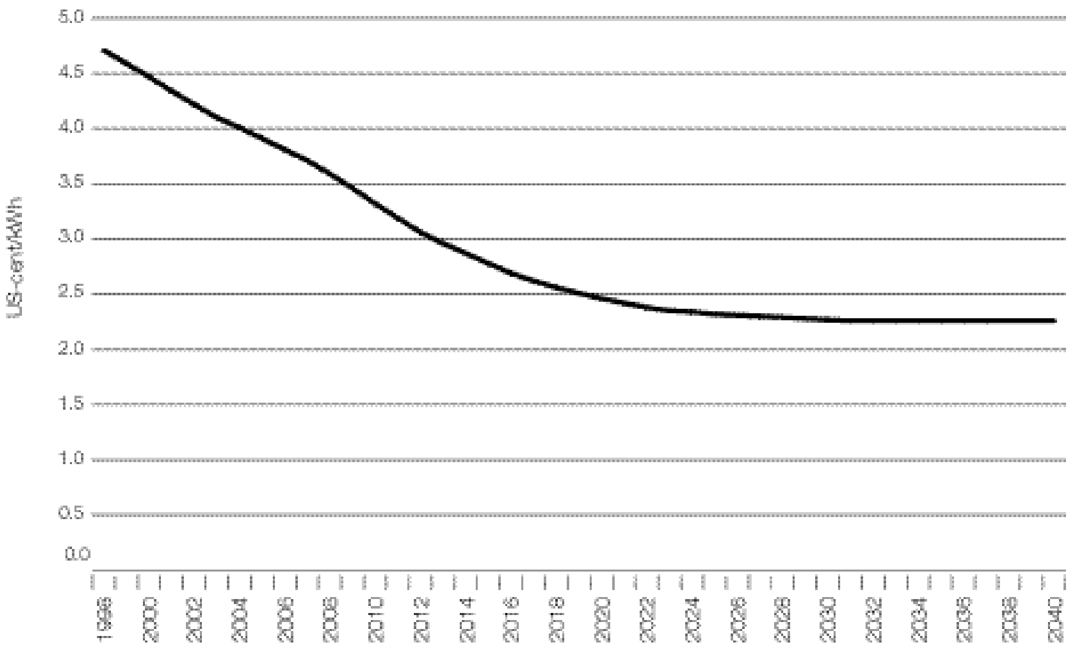


Annual Installation and Replacement

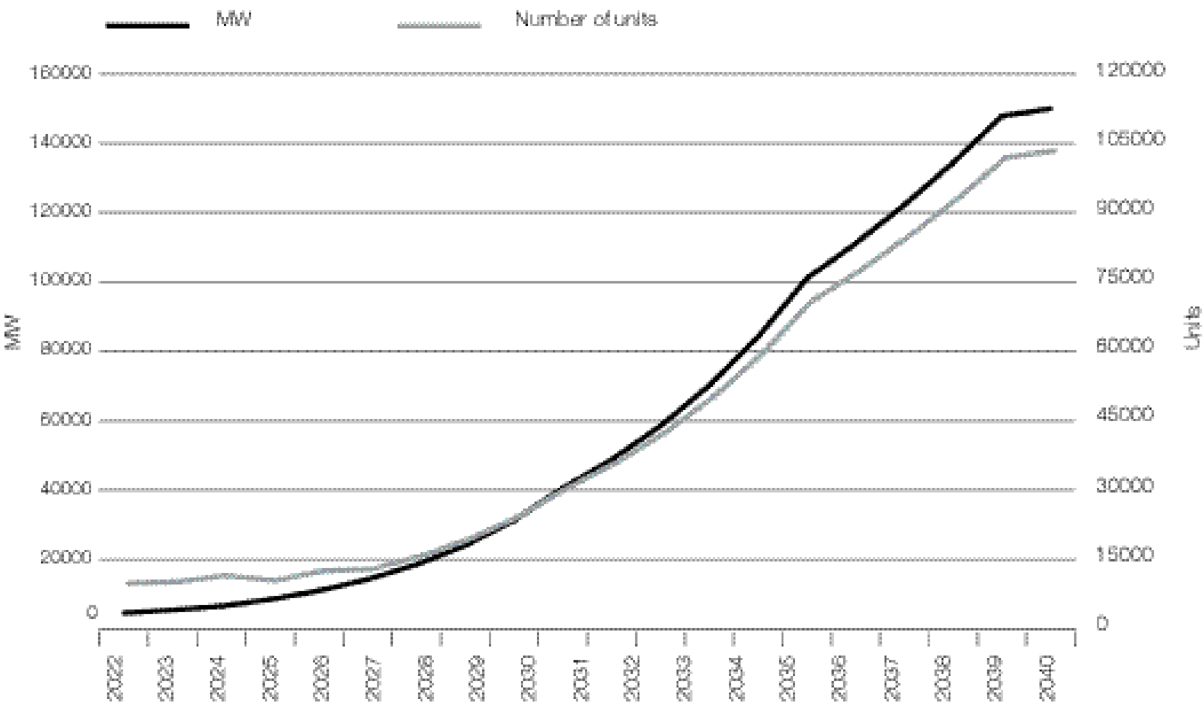


APPENDIX 3 – Graphs showing penetration/annual added capacity and replacement (1999-2040)

Cost Reduction per kWh

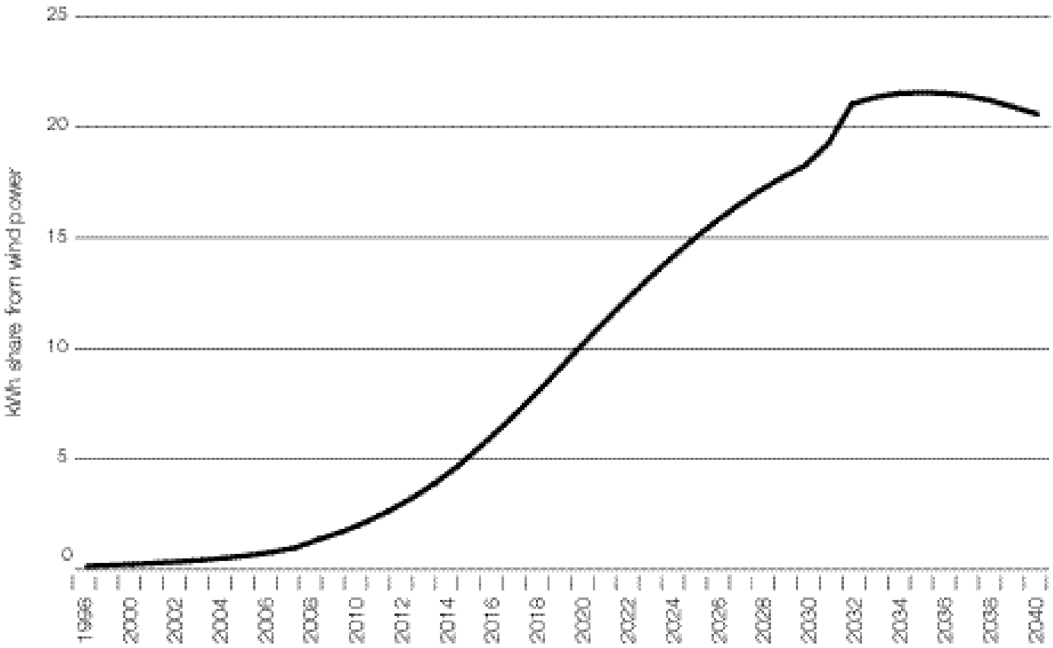


Replacement (MW)



APPENDIX 3 – Graphs showing penetration/annual added capacity and replacement (1999-2040)

Penetration Curve (kWh) – % of World consumption



Penetration Curvevs (1950-1997) Hydro and Nuclear Power

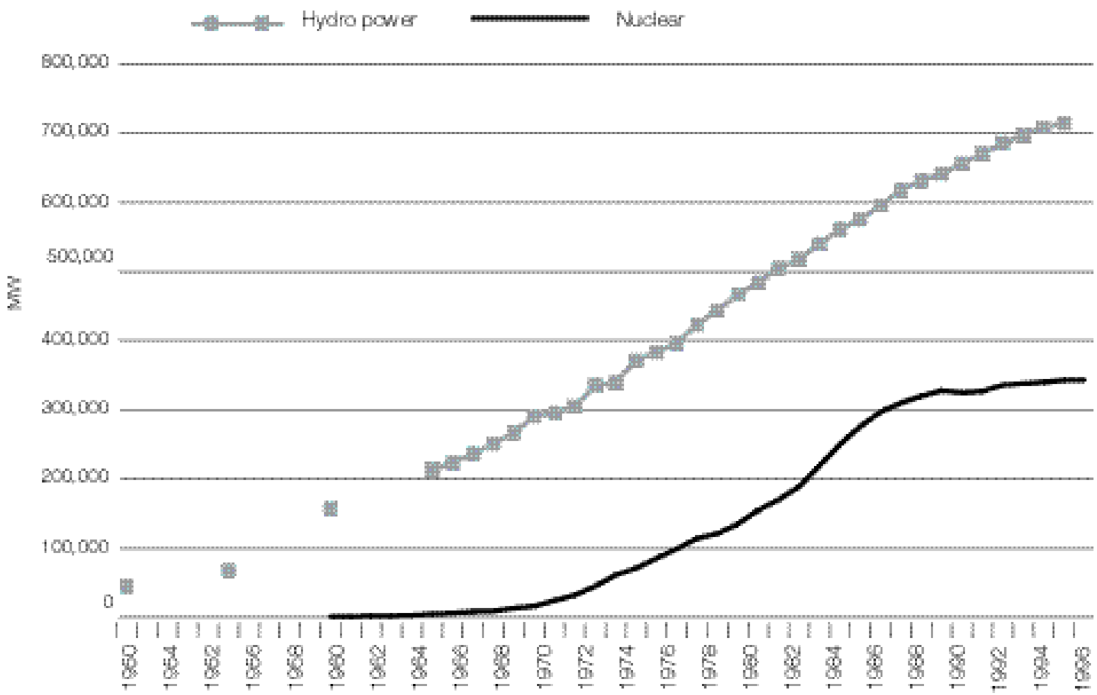


Table 1 – Decrease in the “labour content” of 1 MW wind power

Job -year	1998	2010	2020
Jobs/MW – Manufacturing	17	12	9.5
Jobs/MW – Installation	5	3.5	2.8
Total Jobs/MW	22	15.5	12.3
Total Jobs / USD Mill	22	22	22

Source: Danish Wind Turbine Manufacturers Association (1998) and “progress ratios” from the “10 % Scenario”, BTM Consult ApS, May 1999

Issues and Assumptions Related to Global Wind Energy Employment

1. Local site conditions and infrastructure can have a significant impact on the actual employment figures, for example through poor infrastructure or remote sites which are more expensive to develop. Even within Europe, the construction cost (and related employment) is twice as high in mountainous regions such as Wales and Scotland as in lower-lying Denmark and Germany.

2. General assumptions on regional differences The OECD regions will be able to provide all production capacity and services within their region, even though it might be unevenly distributed. The Asian regions are likely to have 20 % higher employment, due to lower process efficiency, at least in the first decade. On the other hand it is likely that they will have to import some 20 % of hardware from outside their own region.

The Transition Economies will also have higher employment – some 20 % – due to lower process efficiency, but they will be able to produce all components within their region. The same assumption seems valid for Latin America. The Middle East and Africa are estimated to be dependent on the highest import rate, making their employment figures a little overestimated. China is expected to get all its production capacity within the country, but the employment rate will also be higher due to lower process efficiency.

3. Surplus investment and derived employment from establishing the appropriate electrical infrastructure is not included. For the Asian regions, Latin America and the Transition Economies there is an urgent need for significant improvements and extensions of their grid systems. These infrastructure improvements will have to be carried out with or without wind power being implemented on the basis of the IEA projections for increases in demand.

4. Impact from offshore installations The specific higher employment and investment per MW offshore is not taken into account. This will have an impact on the figures for OECD-Europe, where the major part of offshore development is expected to take place.

Table 2 – Future investment and employment, 1999-2020

Year	Annual Installation (MW/year)	Cost (US$/kW)	Investment (US$ billion/year)	Cumul. Investment (US$ billion)	Employment (Job-year)
1998	2,600	1,000	2,600	2,600	57,200
1999	3,120	975	3,041	5,641	66,910
2000	3,744	948	3,551	9,193	78,126
2001	4,493	921	4,139	13,332	91,062
2002	5,391	897	4,834	18,166	106,352
2003	6,470	871	5,636	23,802	123,991
2004	8,411	852	7,164	30,966	157,612
2005	10,934	830	9,072	40,038	199,582
2006	14,214	810	11,508	51,546	253,170
2007	18,478	787	14,540	66,086	319,882
2008	24,021	762	18,298	84,384	402,551
2009	31,228	734	22,935	107,319	504,580
2010	40,596	705	28,640	135,959	630,084
2011	48,715	677	33,000	168,959	725,992
2012	58,458	650	38,010	206,969	836,217
2013	70,150	629	44,155	251,124	971,418
2014	84,180	609	51,285	302,409	1,128,265
2015	101,016	590	59,556	361,965	1,310,228
2016	111,117	572	63,549	425,514	1,398,088
2017	122,229	556	67,939	493,454	1,494,667
2018	134,452	544	73,090	566,543	1,607,970
2019	147,897	532	78,711	645,254	1,731,649
2020	150,000	522	78,339	723,594	1,723,461
Total				723,594	

Note; It is assumed that employment is directly proportional to the investment, thus employment increases along with the progress according to the progress ratios and cost reductions.

APPENDIX 5

Table 1 – Carbon dioxide reduction from the 10% Scenario

Year	Cumulative (MW)	Production (TWh)	CO2 Reduction (million tonnes/year)	CO2 Reduction (cumulative million tonnes)
1998	10,153	22.2	13.3	13.3
1999	13,273	29.1	17.4	30.8
2000	17,017	37.3	22.4	53.1
2001	21,510	47.1	28.3	81.4
2002	26,901	58.9	35.3	116.8
2003	33,371	73.1	43.8	160.6
2004	41,781	91.5	54.9	215.5
2005	52,715	115	69	285
2006	66,929	147	88	373
2007	85,407	187	112	485
2008	109,428	268	161	646
2009	140,656	345	207	853
2010	181,252	445	267	1,120
2011	229,967	564	338	1,458
2012	288,425	707	424	1,883
2013	358,575	880	528	2,410
2014	442,755	1,086	652	3,062
2015	543,771	1,334	800	3,862
2016	654,888	1,606	964	4,826
2017	777,117	1,906	1,144	5,970
2018	911,569	2,236	1,342	7,311
2019	1,059,466	2,599	1,559	8,870
2020	1,209,466	2,967	1,780	10,650
2021	1,354,973	3,323	1,994	12,644
2022	1,499,582	3,678	2,207	14,851
2023	1,643,112	4,030	2,418	17,269
2024	1,784,702	4,378	2,627	19,896
2025	1,923,768	4,719	2,831	22,727
2026	2,059,554	5,052	3,031	25,758
2027	2,191,077	5,374	3,225	28,983
2028	2,317,055	5,683	3,410	32,393
2029	2,435,828	5,975	3,585	35,977
2030	2,545,232	6,243	3,746	39,723
2031	2,646,516	6,491	3,895	43,618
2032	2,738,058	7,196	4,317	47,935
2033	2,817,908	7,405	4,443	52,379
2034	2,883,729	7,578	4,547	56,926
2035	2,932,713	7,707	4,624	61,550
2036	2,971,595	7,809	4,686	66,236
2037	2,999,366	7,882	4,729	70,965
2038	3,014,914	7,923	4,754	75,719
2039	3,017,017	7,929	4,757	80,476
2040	3,017,017	7,929	4,757	85,233

The industry's ability to manage high growth rates

Even with a sufficient wind potential and demand for electricity justifying a penetration as described in our scenario, as well as the correct market conditions in place in all regions of the world, it is still relevant to ask:

- Will the wind power industry be able to expand its capacity that fast over a short period of time?
- Are average growth rates of 30 % or so for seven years in a row possible at all – and how?

It is not possible to give exact answers to these crucial questions but we have tried to assess, on the basis of what has happened in the past and the situation in 1999, what development patterns can be expected in future markets.

Past experience and technical developments
The actual growth rates for new installations around the world, year by year since 1993, are shown in Table A6-1 below.

The average growth rate of 40 % over a period of six years is very impressive, especially when it is compared to other technological developments. This magnitude of growth equals that of modern IT-technology. It is particularly unusual for a complex heavy industry like that involved in the design, manufacture and installation of wind turbines. The wind power industry is also concentrated in a relatively small group of companies which have generally shown an ability to respond to market signals, for example by utilising the potential of new regulatory initiatives, responding to the demand from customers for new technical requirements, supplying larger size turbines and developing turbine designs which satisfy special local conditions and/or legislative requirements.

Another trend has been the merging of companies into larger units, enabling them to cover design and marketing at a higher level in a competitive market. Up until 1992-93 financing facilities for their customers was a major constraint. Today, operating track records and a continuously declining price for wind turbines has convinced financial companies not only to make capital available for investment in wind power plants, but also to provide equity capital for high risk investment directly in the manufacturing industry. Of the three top wind energy companies in the world, two went public on the Copenhagen stock exchange in order to attract new capital. The third company was taken over by the world's number two in the gas industry, Enron Corporation.

Even though they are still small companies measured on a power sector scale, their expansion recently has been recognised by the financial world and big industrial groups within the power industry. Table A6-2 shows the development over the past three years of the "Top 10" companies in the world.

Table A6-2 above shows an industry where:

- The four largest companies – NEG Micon, Vestas, Enron and Enercon share 60 % of the total market. If subsidiaries and associated companies are included, these four share a total of 73.2 % (Tacke, Wind World and Gamesa are fully or partly owned by Enron, NEG Micon and Vestas respectively).
- The four leading companies have demonstrated average annual growth rates in the range 26% to 51% since 1995.
- Several of the smaller companies (2-5 % market share) have the potential for growth to the size of the "big four".

Sub-suppliers

The structure in the industry is that most of the turbine manufacturers depend on a large group of sub-suppliers for the supply of gearboxes, drive train components, roller bearings, electrical generators, transformers,

Table A6-1 : Growth of world wind energy market 1994-1998

Year	Installed new capacity sales (MW)	Growth in annual sales (%)	Cumulative installation by year end (MW)	Growth of cumulative capacity installed (%)
1993	480	108	2,758	
1994	730	52	3,488	26.5
1995	1,290	77	4,778	37
1996	1,292	2	6,070	27
1997	1,566	21	7,636	26
1998	2,597	66	10,153	33
Average growth in five years (1994-1998)		40.2%		29.7%

Source: BTM Consult ApS, World Market Update 1998, April 1999

Table A6-2: Market shares in 1996, 1997 and 1998 and average annual growth rates

Company	Sales 1996(MW)	Share in 1996 (%)	Sales (997(MW)	Share in 1997 (%)	Sales 1998 (MW)	Share in 1998 (%)	Average annual growth rate 1995-1998 (%)
NEG Micon	-	-	309	19.7	527	20.3	30
Micon	134	10.4	-	-	-	-	30
Nordtank	110	8.5	-	-	-	-	30
Vestas	228	17.6	290	18.5	385	14.8	26.6
Enercon	153	11.8	223	14.2	334	12.8	26.8
Bonus	117	9.1	222	14.2	149	5.7	19.3
Gamesa Eolica	79	6.1	93	5.9	171	6.6	(incl. in Vestas)
Made	17	1.3	75	4.8	105	4.0	-
Nordex	38	2.9	67	4.3	131	5.0	33.8
Desarrollos Eolicos	20	1.5	54	3.4	27	1.0	-
Enron/Zond	11.5	0.9	38	2.4	350	13.5	51.8
Tacke	83	6.4	29	1.8	74	2.8	
Wind World	28.3	2.2	29	1.9	61	2.4	(incl. inNEG Micon)
NEPC	36	2.8	0	-	0	-	-
Others.	137	10.6	113	7.2	218	8.4	44
Total	**1,192**	**92**	**1,542**	**98**	**2,530**	**97**	**(26.3)** acc. to Table A6-1

Source: BTM Consult ApS, March 1999 (last column added May 1999)

Note: The figures for average growth are based on the total for company groups in 1998, compared to figures for their individual entities in1995 - even though they were not owned by the group at that time. Total average growth of 26.3 % in this period includes a year with no growth (1995-1996) electrical equipment, brake systems and electronic software and hardware. Among these sub-suppliers are several multinational companies which also supply the traditional power industry, including ABB, Siemens, Valmet, Flender and SKF. These major companies are considered to possess the capability and financial strength to meet increased demand from the wind turbine industry in coming years.

The only "new industry" among the sub-suppliers is in the blade manufacturing area, with LM Glasfiber the dominating company with a market share of around 40 %. LM has also shown the ability to expand through establishing joint ventures around the world.

Through the introduction of larger commercial wind turbines in the 600-1,000 kW class, most manufacturing companies have placed themselves in a better position to ensure rapid growth. Recent developments in turbine concepts have been focussed on the design of MW-scale turbines and features for improved compliance with utility grid systems. Table A6-3 shows the status of MW-scale turbines by the end of 1998. It is worth noting that some 420 MW of installed capacity in this range of wind turbine generators has been installed during 1998, accounting for 16 % of the total for the year. The expectations of a European offshore wind power market emerging by the turn of the century have encouraged this development.

Recent developments include a decision by Vestas to upgrade their 1.65 MW turbine to a 1.8 MW with the same rotor size. Bonus Energy has been the first manufacturer to introduce a 2 MW size turbine to the market; the first prototype was commissioned just before the end of 1998. Enron/Tacke has also recently introduced a 2 MW size, specifically designed for the offshore market. The average size of wind turbine in the commercial market has grown from approximately 400 kW in 1995 to 700 kW in 1998.

Expanding manufacturing capacity

A brief survey among some of the leading companies in the wind energy industry has led to the following estimates of today's manufacturing capacity:

- The industry expects to be able to expand its manufacturing capacity by at least 25-30 % per year for up to ten years ahead – if the demand is there.
- Manufacturing capacity by the end of 1999 is expected to be in the order of 5,000 to 7,000 MW per year. This is well above the annual demand expected up to 2003 (5,500 MW/year in BTM Consult's latest forecast).
- Manufacturing facilities for wind turbine manufacturing and blade production are estimated to be in the order of 400-450,000 square metres, sufficient for a production of some 4-5,000 MW/year.
- The major constraints for keeping up with demand at a rate of 30 % + per year, will be the sub-suppliers' ability to increase their supplies to the industry fast enough. However, both gearbox and blade suppliers have announced significant expansion of capacity during 1998.

Technology transfer as a boost for manufacturing capacity

If an emerging market is considered politically stable and the size of the total market is in the order of 100-200 MW per year, the manufacturers have demonstrated their willingness to create manufacturing through a locally based subsidiary or by creating of a joint venture with local partners. In 1993 a technology agreement was reached between Micon and NEPC, enabling the latter to gain a market position of 40 % in India within two years. Another example is Vestas in Spain, where the Danish company established local production through a joint venture with Gamesa and another Spanish company. This local manufacture included production of blades. In 1998 this new company ranked fifth in the world with a market share of 6.6 %. All the major manufacturers have established local manufacturing abroad at different levels or are considering such expansion in emerging markets in South America and Asia. The different "routes" to be taken in a potential expansion of the wind industry are shown in outline in the following table.

Conclusions on potential growth

Based on recent experience and ongoing expansion during 1999, it is likely that the industry will be able to meet growth in demand of some 30 % per annum for at least five years ahead. Manufacturing capacity is already 5-6,000 MW/year, although to some extent limited by lack of fast supplies from sub-suppliers. There seems to be ready venture capital available to meet the industry's demands. A clear signal from the industry, however, is that they want to see a politically stable framework for wind power development in emerging markets before they enter local manufacturing through establishing joint ventures. With today's wind turbine generator concepts and related manufacturing technology, the most advanced companies can replicate their manufacturing facilities and quality standards in a new market within 2-3 years.

Based on these observations, it is likely that the industry as a whole will be able to expand at a rate of 25-30 % per year for five to seven years ahead. An important factor is the likely take-off of offshore development from 2001 in Europe, as that market is assumed to be an additional "bonus" on top of the generally high expansion on land. This means that the wind energy industry will be able to more than comply with the growth rates stipulated in the 10 % scenario. However, a prerequisite for such growth is the establishment of a strong, stable and demanding market.

Table A6-3: Commercially installed MW-size wind turbines

	Units	Installed (MW)	Average size (MW/unit)
Denmark	20	21	1.05
Germany	405	513	1.27
Luxembourg	1	1	1
Netherlands	27	27	1
Norway	1	1.65	1.65
Spain	1	1	1
USA	5	5.6	1.12
Total	**460**	**570**	**1.24**

Source: BTM Consult ApS, March 1999

Table A6-4: Routes for expanding the world's manufacturing capacity

Typical routes for expansion in a dynamic industry	Case 1	Case 2	Case 3
	"Steady growth" in an expanding industry (reference case)	High growth - by organic growth or by gains from mergers	High growth - combined with efficient technology transfer
Expected annual growth rates	10 - 15 % p.a	20 - 25 %	25 -35 %
Comment	Evidence from the market indicates that today's wind industry is moving from Case 2 to Case 3, which is necessary if it is to comply with the growth rates in the "10 % Scenario".		

BTM Consult ApS - May 1999

APPENDIX 6 – Global Installed Wind Capacity

Table 2-3 : Installed capacity in 1997 and 1998

Cumulative	MW 1997	Installed MW 1998	Cumulative MW 1998
USA	1,611	577	2,141
Canada	26	57	83
Mexico	2	0	2
South & Central America	42	24	66
Total America	1,681	658	2,292
Denmark	1,116	310	1,420
Finland	12	6	18
France	13	8	21
Germany	2,081	793	2,874
Greece	29	26	55
Ireland (Rep.)	53	11	64
Italy	103	94	197
Netherlands	329	50	379
Portugal	39	13	51
Spain	512	368	880
Sweden	122	54	176
UK	328	10	338
Others: Belgium, Czech Rep., Slovak Rep., Norway, Austria, Switzerland, Turkey, East European countries etc.	57	23	80
Total Europe	4,793	1,766	6,553
China	146	54	200
India	940	82	992
Others: Korea, Japan, Malaysia, Indonesia, Thailand, Vietnam etc.	22	11	33
Total Asia	1,108	147	1,224
Australia & New Zealand	8	26	34
Pacific Islands	3	0	3
North Africa: Egypt, Ethiopia, Libya, Tunis, Algeria, Cap Verde, Morocco.	9	0	9
Middle East: Jordan, Syria, Israel, Saudi Arabia, Iran, Iraq.	18	0	18
Former Soviet Union	19	1	19
Total other continents and areas:	57	27	83
Annual MW installed		2,597	
Cumulative MW installed in the world	7,639		10,153

Source: BTM Consult ApS, "World Market Update 1988", March 1999

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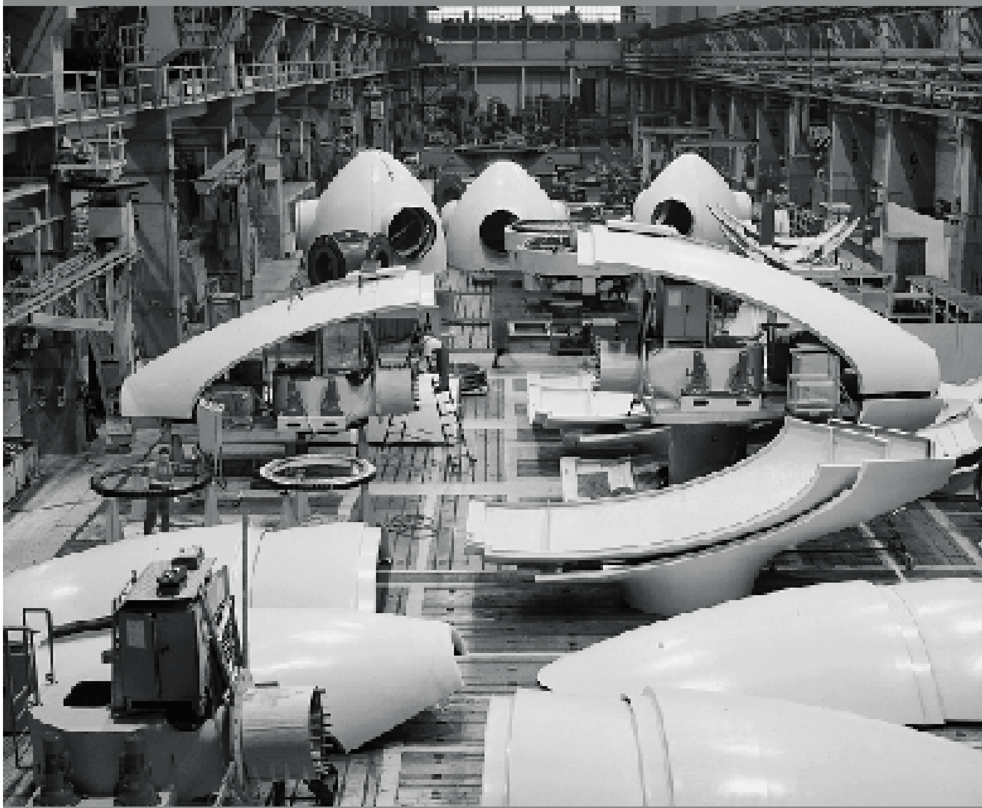

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