FOREWORD

by
Hans van Steen
Head of Unit, Regulatory Policy and Promotion of Renewable Energy,
Directorate General for Energy and Transport (DG TREN), European Commission

It is a pleasure for me to introduce the new edition of *Wind Energy – The Facts*, produced by the European Wind Energy Association (EWEA) and supported by the European Commission in the framework of the Intelligent Energy Europe programme.

At the European Union (EU) level, the challenges related to energy and climate change are at the very top of the political agenda and, more than ever before, wind energy is proving its potential as an important part of the solution. Through its concrete contribution to clean and secure power generation, wind ensures that an increasing amount of electricity is produced without using fossil fuels, without using precious fresh water for cooling purposes, and without emitting greenhouse gases or harmful air pollutants.

The deployment of wind energy continues to be a success story in the EU. More and more Member States have joined the initial front-runners, and wind continues to be one of the fastest growing forms of electricity generation in Europe. Wind turbine technology continues to improve, larger and more efficient technologies are being deployed, and offshore applications are coming on-stream.

The European Commission is convinced that there is a large untapped potential of renewable energy in Europe. The agreed target of a 20 per cent share of renewable energy in the EU's energy mix in 2020 is thus at the same time both ambitious and achievable.

But meeting the target will not become a reality without strong commitments at all levels, including national governments and the renewables industry itself. Large-scale integration of wind into electricity grids and markets poses significant challenges to the sector – challenges that will require researchers, transmission system operators, energy companies, regulators, policymakers and other stakeholders to work closely together and constructively consider appropriate solutions.

This publication provides an excellent, highly readable and comprehensive overview of the diverse issues of relevance to wind power. Given the growing importance of wind in the European energy sector, it is a useful reference document, not just for the sector itself, but also more widely for policy- and decision-makers.

EWEA FOREWORD

by
Arthouros Zervos
President, European Wind Energy Association

It has been five years since I wrote the foreword to the 2004 edition of *Wind Energy – The Facts*, and in that short time there have been major, positive changes in the European wind power industry. For the most part, the environmental, regulatory, technological, financial and political questions surrounding the industry in 2004 have now been satisfactorily answered.

Cumulative installed wind capacity is perhaps the most relevant proof of this amazing success story. By the end of 2003, the EU-15 had installed more than 28,000 megawatts (MW) of wind turbine capacity. By the end of 2007, the enlarged EU-27 had in excess of 56,000 MW of capacity.

These 56,000 MW met 3.7 per cent of total EU electricity demand, provided power equivalent to the needs of 30 million average European households and avoided 91 million tonnes of carbon dioxide emissions. In addition, there were billions of euros saved on imported fuel costs in 2007, while more than €11 billion was invested in installing wind turbines in Europe.

A deepening political concern has also emerged over the past five years with regard to climate change and energy. Politicians are seeking viable and powerful solutions to the challenges of escalating oil prices, depleting fossil fuel reserves, dependence on foreign energy supplies and the potential ravages of global warming. Now, more than ever, our elected leaders are looking for solutions to these complex and critically important issues.

As a result, the EU has set a binding target of 20 per cent of its energy supply to come from wind and other renewable resources by 2020. To meet this target, more than one-third of European electrical demand will need to come from renewables, and wind power is expected to deliver 12 to 14 per cent (180 GW) of the total demand. Thus wind energy will play a leading role in providing a steady supply of indigenous, green power.

We feel it is the right time to update *Wind Energy – The Facts*, in order to address further changes in this rapidly expanding industry, both in Europe and globally. Both market and turbine sizes have grown immeasurably since 2003, prompting an entirely new set of considerations. With all this additional power being created, issues such as grid access, new and strengthened transmission lines, and system operations have to be dealt with in a fair, efficient and transparent way. The relatively new offshore wind industry has astonishingly rich potential, but needs to be helped through its infancy, and the supply chain bottlenecks created by this rapid growth still need to be overcome.

I hope this latest edition of *Wind Energy – The Facts* helps to provide a pathway to a truly sustainable future. I remain confident that the wind power industry will overcome the challenges it faces and achieve even greater success.

Arthouros Zervos
President, EWEA

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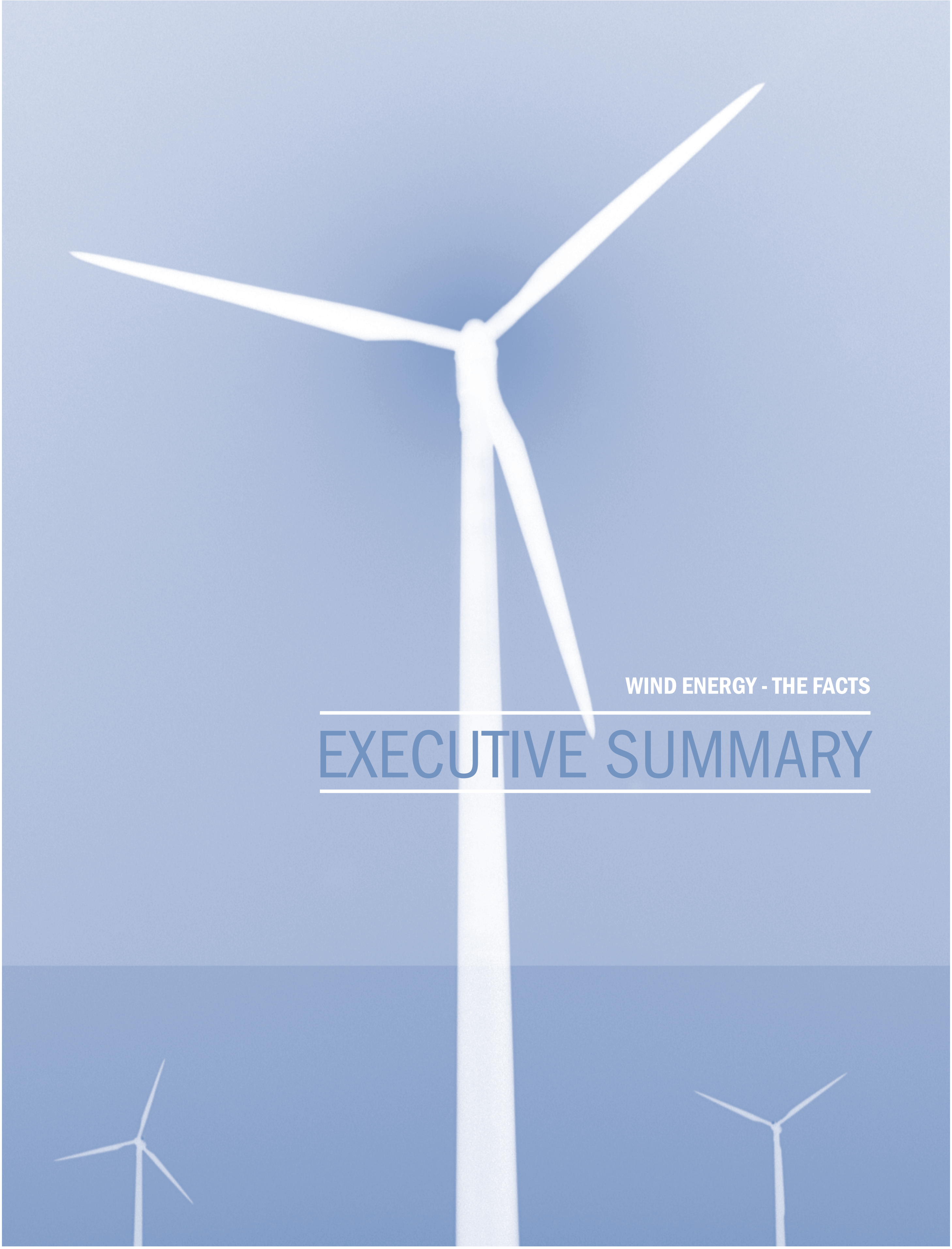
The information in *Wind Energy – The Facts* does not necessarily reflect the formal position of the European Wind Energy Association or the European Commission.

As the wind energy sector is highly dynamic and in continual development, the data and figures in this volume, correct in October 2008, may become slightly out-of-date as of 2009. All the most recent statistics and information can be found on the Wind Energy – The Facts website: www.windfacts.eu.



WIND ENERGY - THE FACTS

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

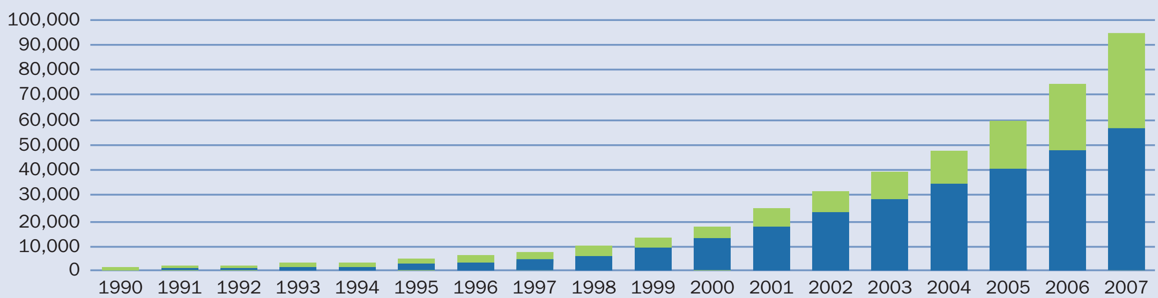
Since the last edition of *Wind Energy – The Facts* was published in February 2004, the wind energy sector has grown at an astonishing rate and is now high on the political agenda. With the looming energy crisis, calls are increasing for an immediate and concrete solution to the many energy and climate challenges the world is currently facing – and wind energy offers just this.

In order to facilitate informed choices and policy decisions, a clear and profound understanding of the wind power sector is required. This volume aims to contribute to this knowledge dissemination by providing detailed information on the wind power sector. *Wind Energy – The Facts* provides a comprehensive overview of the essential issues concerning wind power today: wind resource estimation, technology, wind farm design, offshore wind, research and development, grid integration, economics, industry and markets, environmental benefits, and scenarios and targets.

Since 2004, wind energy deployment has risen dramatically. Global installed capacity increased from 40,000 megawatts (MW) at the end of 2003 to 94,000 MW at the end of 2007, at an average annual growth rate of nearly 25 per cent. Europe is the undisputed global leader in wind energy technology. Sixty per cent of the world's capacity was installed in Europe by the end of 2007, and European companies had a global market share of 66 per cent in 2007. Penetration levels in the electricity sector have reached 21 per cent in Denmark and about 7 and 12 per cent in Germany and Spain respectively. Achievements at the regional level are even more impressive: the north German state of Schleswig-Holstein, for example, has over 2500 MW of installed wind capacity, enough to meet 36 per cent of the region's total electricity demand, while in Navarra, Spain, some 70 per cent of consumption is met by wind power.

A huge step forward was taken in March 2007, when EU Heads of State adopted a binding target of 20 per cent of energy to come from renewables by 2020. And in January 2008, the European Commission released a renewables legislation draft, proposing a stable and flexible EU framework, which should ensure a massive expansion of wind energy in Europe. If such positive policy support continues, EWEA projects that wind power will achieve an installed capacity of 80,000 MW in the EU-27 by 2010. This would represent

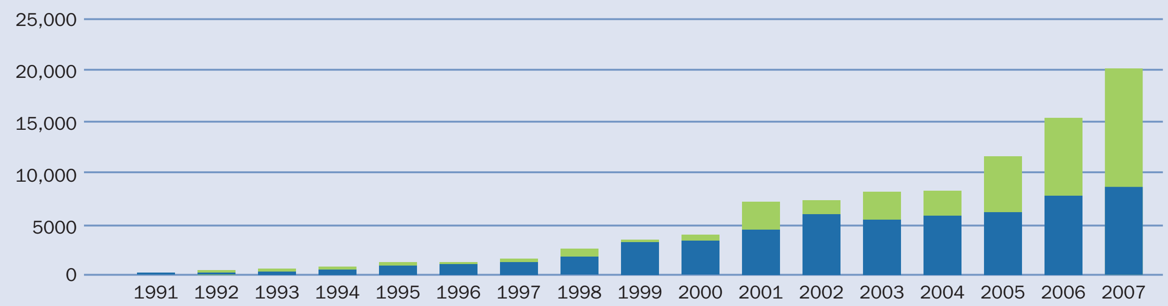
Figure S.1: Global cumulative wind power capacity, 1990–2007 (in MW)



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Rest of the world	1304	1354	1477	1590	1848	2324	2628	2883	3700	3916	4470	7133	8150	10,940	13,248	18,591	26,102	37,587
EU	439	629	844	1211	1683	2497	3476	4753	6453	9678	12,887	17,315	23,098	28,491	34,372	40,500	48,031	56,535
Total	1743	1983	2321	2801	3531	4821	6104	7636	10,153	13,594	17,357	24,448	31,248	39,431	47,620	59,091	74,133	94,122

Source: GWEC/EWEA (2008)

Figure S.2: Global annual wind power capacity, 1991–2007 (in MW)



	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Rest of the world	50	123	113	258	476	304	255	817	216	554	2663	1357	2671	2369	5327	7715	11,519
EU	190	215	367	472	814	979	1277	1700	3225	3209	4428	5913	5462	5838	6204	7592	8554
Total	**240**	**338**	**480**	**730**	**1290**	**1283**	**1532**	**2517**	**3441**	**3763**	**7091**	**7270**	**8133**	**8207**	**11,513**	**15,307**	**20,073**

Source: GWEC/EWEA (2008)

an overall contribution to electricity supply of 5 per cent. By 2020, this figure is expected to increase to 12–14 per cent, with wind power providing energy equal to the demand of 107 million average European households.

Part I: Technology

Part I covers all aspects of the technology of the wind industry, which has made rapid advances in all areas. Much has been learned, but there is much still to be discovered, both in fundamental meteorology, aerodynamics and materials science and in highly applied areas such as maintenance strategies, wind farm design and electricity network planning. And there are still untried concepts for turbine design which may be worth serious consideration. This part describes the fundamentals of wind technology, the current status and possible future trends.

WIND RESOURCE ESTIMATION

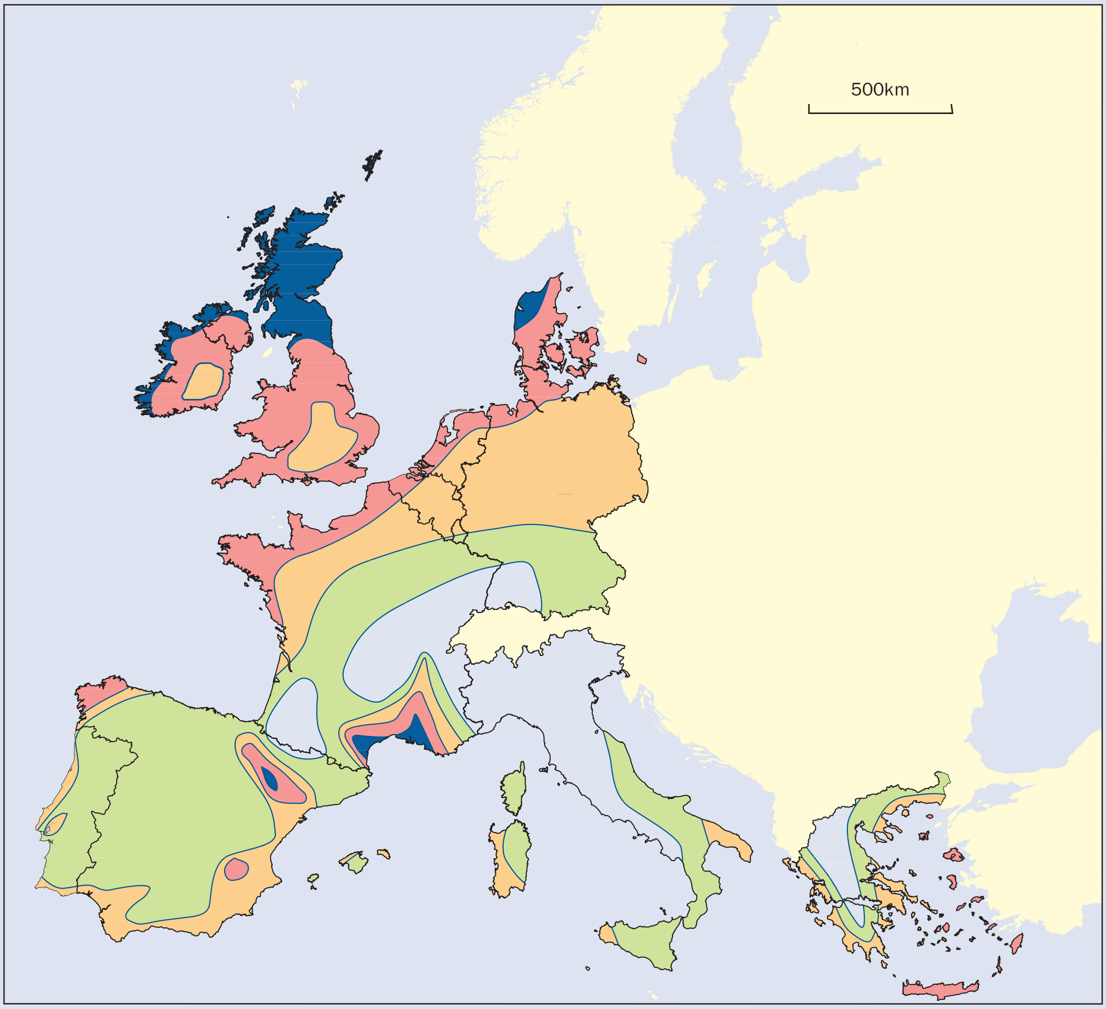
The methods for carrying out wind resource estimation are well established. Chapter I.1 describes wind resource estimation for large areas, which is carried out in order to establish both the available resource in a region and the best areas within that region. It also covers wind resource and energy production estimation for specific sites. The accuracy of the energy production estimate is of crucial importance both to the owner of the project and to organisations financing it, and the chapter explains the many factors which can affect energy production.

Forecasting is also covered, in Chapter I.2, as this is now an important part of the wind industry. Depending on the structure of the electricity market, the owner of the project or the purchaser of the energy may be able to reap significant financial benefits from the accurate forecasting of wind production. Operators of electricity systems with high wind penetration also need forecasts in order to optimise the operation of their systems.

WIND TURBINE TECHNOLOGY

The rapid technical advances are most apparent in wind turbine technology. Chapter I.3 shows how turbine size, power and complexity have developed

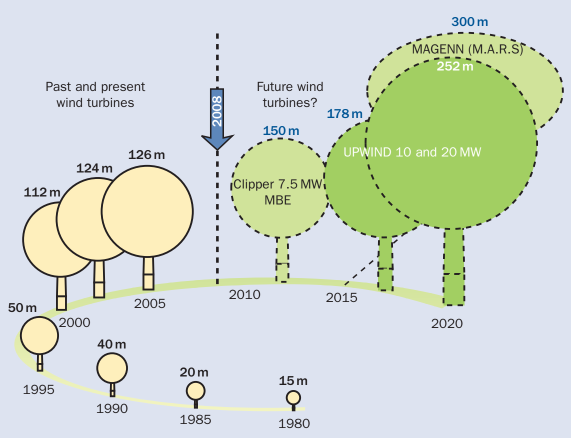
Figure S.3: European Wind Atlas, onshore



Wind resources at 50 metres above ground level for five different topographic conditions										
	Sheltered terrain		Open terrain		At a sea coast		Open sea		Hills and ridges	
	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}
	>6.0	>250	>7.5	>500	>8.5	>700	>9.0	>800	>11.5	>1800
	5.0–6.0	150–250	6.5–7.5	300–500	7.0–8.5	400–700	8.0–9.0	600–800	10.0–11.5	1200–1800
	4.5–5.0	100–150	5.5–6.5	200–300	6.0–7.0	250–400	7.0–8.0	400–600	8.5–10.0	700–1200
	3.5–4.5	50–100	4.5–5.5	100–200	5.0–6.0	150–250	5.5–7.0	200–400	7.0–8.5	400–700
	<3.5	<50	<4.5	<100	<5.0	<150	<5.5	<200	<7.0	<400

Source: Risø DTU

Figure S.4: Growth in size of commercial wind turbine designs



Source: Garrad Hassan

extremely fast, best evidenced by the increase in commercial turbine size by a factor of around 100 in 20 years (Figure S.4). Wind turbines may appear to be simple machines, but there are some fundamental requirements which make this branch of engineering unlike any other:

- The machine has to operate as a power station, unattended, and provide more to the electricity network than simply energy.
- The wind is variable on timescales from seconds to years, which introduces uncertainty into everything from mechanical loads to energy production.
- The technology has to compete on cost of energy against other renewables and against conventional generation.

Chapter I.3 thus discusses the evolution of wind turbine design and explains why three-bladed, upwind, variable-speed, pitch-regulated turbines currently predominate. The principal design drivers are now grid compatibility, cost of energy (which includes reliability), acoustic emissions, visual appearance and suitability for site conditions.

However, there are still many unresolved technical issues. For example, large turbines currently in production include:

- concepts with large-diameter, slow-speed generators;
- concepts with high-speed generators and gearboxes; and
- intermediate arrangements with medium-speed generators and reduced stages of gearing.

Similarly, it is perhaps surprising that the optimum size of a wind turbine for 'standard' onshore wind farms is not yet obvious. The chapter explains some of these technical issues, and concludes by reviewing some radical alternative concepts.

WIND FARM DESIGN

Chapter I.4 describes how wind turbines are grouped into wind farms, the factors affecting siting and how they are built. Wind farm design is a critical area for cost reduction and public acceptability, both onshore and offshore, especially with some now being bigger than large conventional electricity-generating plants.

The arrangement of wind turbines within the wind farm clearly affects not only the energy production, but also the visual appearance and the noise influence on neighbours. This chapter explains how the layout can be optimised to take account of such constraints, using software designed specifically for the wind industry.

The chapter also discusses the important issues in 'balance of plant' design, including civil and electrical works. As the wind industry gains experience in constructing projects in different conditions, the costs and other important issues are becoming clearly understood, and the risks should be no greater than other civil engineering or power station projects of similar size.

OFFSHORE WIND POWER

Chapter I.5 covers offshore wind, and in particular extends the discussion of onshore issues in

Chapters I.2–I.4 to the offshore case. Although this market is currently substantially smaller than the onshore one, it is now a fundamental part of several nations' energy policies, and expectations are high. The offshore wind market is characterised by projects which are significantly larger and more risky than most onshore projects, and it appears likely that different organisations will develop and construct these projects. Special vessels and techniques for erecting turbines have been developed, and the means of access to offshore turbines has emerged as a major issue influencing cost, availability and safety.

The turbine technology too is different for offshore projects: there are strong reasons why individual turbine size is significantly larger, and turbines of 5 MW and more are being aimed at this market. More subtle differences in technology are also emerging, due to the different environment and increased requirements for reliability. There is perhaps greater probability of truly innovative designs emerging for the offshore market than for the onshore market, and the chapter concludes by reviewing innovative concepts such as floating turbines.

SMALL WIND TURBINES

At the other end of the scale, Chapter I.6 describes the small and very small wind turbines that are emerging to meet several distinct needs. As well as the traditional areas of rural electrification and providing power to isolated homes, boats and telecommunications facilities, the prospects for significant demand for 'micro-generation' in urban areas is prompting technical developments in small wind turbine design, which could result in significant improvements in the economics. Furthermore, increasing fuel costs are encouraging developments in the technically demanding field of high-penetration wind-diesel systems. This wide range of markets, each with its own characteristics, means that the small wind turbine field shows much greater variety than that of conventional large wind turbines. There is great potential for growth in many of these markets.

RESEARCH AND DEVELOPMENT

Chapter I.7 describes research and development (R&D) efforts in wind technology. A common misunderstanding is to consider wind energy as a mature technology, which could lead to a reduced R&D effort. In addition, the European 20 per cent target for the promotion of energy production from renewable sources poses new challenges. In its recently published Strategic Research Agenda, the European Technology Platform for Wind Energy, TPWind (www.windplatform.eu), proposes an ambitious vision for Europe. In this vision, 300 GW of wind energy capacity is implemented by 2030, representing up to 28 per cent of EU electricity consumption. Moreover, the TPWind vision includes a sub-objective on offshore wind energy, which should represented some 10 per cent of EU electricity consumption by 2030.

An intermediate step is the implementation of 40 GW by 2020, compared to the 1 GW installed today.

R&D is needed to ensure the efficient implementation of the TPWind vision for wind energy so that its targets can be achieved, and TPWind has established R&D priorities in order to implement its 2030 vision for the wind energy sector. Four thematic areas have been identified:

1. wind conditions;
2. wind turbine technology;
3. wind energy integration;
4. offshore deployment and operation.

In order to implement the TPWind 2030 vision and enable the large-scale deployment of wind energy, the support of a stable and well-defined market, policy and regulatory environment is essential. The Market Deployment Strategy includes, amongst other aims, cost reduction and the effective integration of wind into the natural environment.

One main concern is the R&D funding effort. Indeed the total current R&D effort for wind energy in the EU is insufficient to reach European objectives regarding the share of renewable sources of energy in the energy mix and satisfy the Lisbon objectives for growth and jobs.

The most critical component is the European contribution. The Strategic Energy Technology Plan (SET-Plan) proposes a series of instruments to solve this situation, such as the European Industrial Initiatives, which include the European Wind Initiative.

Part II: Grid Integration

Wind power varies over time, mainly under the influence of meteorological fluctuations, on timescales ranging from seconds to years. Understanding these variations and their predictability is of primary importance for the integration and optimal utilisation of wind power in the power system. These issues are discussed in Chapters II.1 and II.2. Electric power systems are inherently variable, in terms of both demand and supply. However, they are designed to cope effectively with these variations through their configuration, control systems and interconnection.

In order to reduce variability, wind plant output should be aggregated to the greatest extent possible. As well as reducing fluctuations, geographically aggregating wind farm output results in an increased amount of firm wind power capacity in the system. Predictability is key to managing wind power's variability. The larger the area, the better the overall prediction of aggregated wind power, with a beneficial effect on the amount of balancing reserves required, especially when gate closure times in the power market take into account the possible accuracy levels of wind power forecasting.

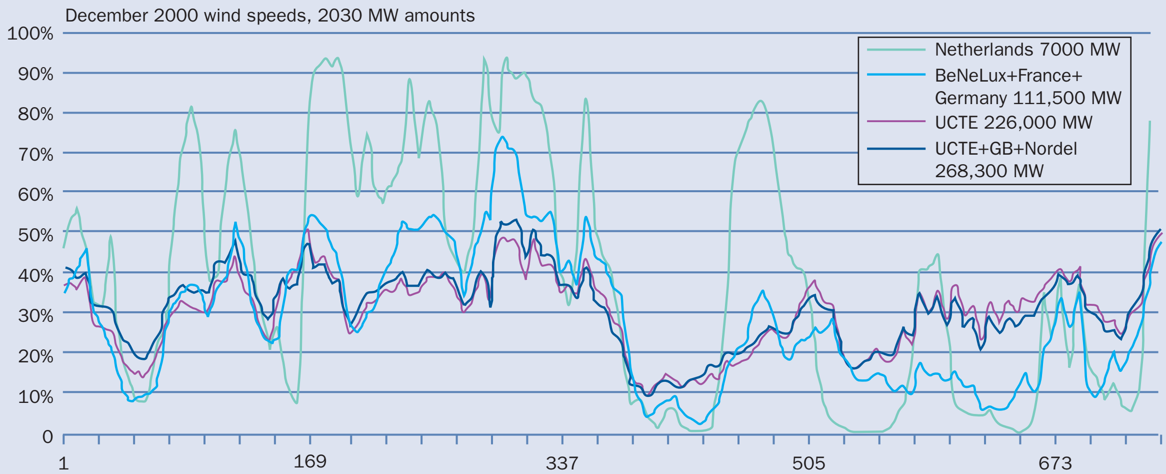
In addition to the advantage of reducing the fluctuations, the effect of geographically aggregating wind farm output is an increased amount of firm wind power capacity in the system.

The large-scale integration of wind energy is seen in the context that wind will provide a substantial share of future European electricity demand. While wind energy covered around 4 per cent of electricity demand in 2008, EWEA targets for 2020 and 2030 are for penetration levels of 12–14 per cent and 21–28 per cent respectively, depending on future electricity demand.

DESIGN AND OPERATION OF POWER SYSTEMS

The established control methods and system reserves available for dealing with variable demand and supply

Figure S.5: Example of smoothing effect by geographical dispersion



Note: The figure compares the hourly output of wind power capacity in four situations, calculated with simulated wind power. The simulations are based on December 2000 wind speeds and wind power capacity estimated for 2030.

Source: www.trade-wind.eu

are more than adequate for dealing with the additional variability at wind energy penetration levels up to around 20 per cent, though the exact level depends on the nature of the specific system. The estimate for extra reserve requirements is around 2–4 per cent of the installed wind power capacity at 10 per cent wind energy penetration, depending on power system flexibility, short-term forecast quality and the gate closure times in the power markets. At higher penetration levels, changes to systems and their method of operation may be required in order to accommodate the further integration of wind energy, and this issue is covered in Chapter II.3. In order to reduce integration efforts and costs, power system design needs to be more flexible. This can be achieved by a combination of flexible generating units, storage systems, flexibility on the demand side, availability of interconnection capacity and more flexible rules in the power market.

Table S.1 gives a detailed overview and categorisation of the power system effects of wind power.

A graphical overview of the various impacts of wind power in the power system is given in Figure S.6, which clearly shows both the local and system-wide impacts and the short- and long-term impacts for the various affected aspects of the power system, including grid infrastructure, system reserves and system adequacy.

GRID INFRASTRUCTURE UPGRADE

Wind energy, as a distributed and variable-output generation source, requires infrastructure investments and the implementation of new technology and grid-management concepts; these are presented in Chapter II.4. The large-scale integration of wind power requires a substantial increase in transmission capacity and other upgrade measures, both within and between the European Member States. Significant improvements can be achieved by network optimisation and other 'soft' measures, but the construction of new lines will also be necessary. At the same time, adequate and

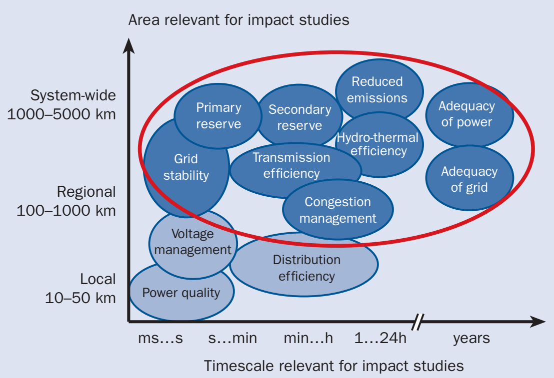
Table S.1: Power system impacts of wind power, causing integration costs

	Effect or impacted element	Area	Timescale	Wind power contribution
Short-term effects	Voltage management	Local/regional	Seconds/ minutes	Wind farms can provide (dynamic) voltage support (design-dependent).
	Production efficiency of thermal and hydro	System	1–24 hours	Impact depends on how the system is operated and on the use of short-term forecasting.
	Transmission and distribution efficiency	System or local	1–24 hours	Depending on penetration level, wind farms may create additional investment costs or benefits. Spatially distributed wind energy can reduce network losses.
	Regulating reserves	System	Several minutes to hours	Wind power can partially contribute to primary and secondary control.
	Discarded (wind) energy	System	Hours	Wind power may exceed the amount the system can absorb at very high penetrations.
Long-term effects	System reliability (generation and transmission adequacy)	System	Years	Wind power can contribute (capacity credit) to power system adequacy.

Source: EWEA

fair procedures need to be developed to provide grid access to wind power even where grid capacity is limited. A transnational offshore grid would not only provide access to the huge offshore resource, but would also improve the cross-border power exchange between countries and alleviate congestion on existing interconnectors. Improving the European networks requires the coordination in network planning to be strengthened at the European level and greater cooperation between all parties involved, especially transmission system operators (TSOs). At the distribution level, more active network management is required. Enhancing the grid's suitability for increased transnational and regional electricity transport is in the interest of both the wind industry and the internal electricity market.

Figure S.6: System impacts of wind power



Note: Issues which are within the scope of Task 25 are circled in red.

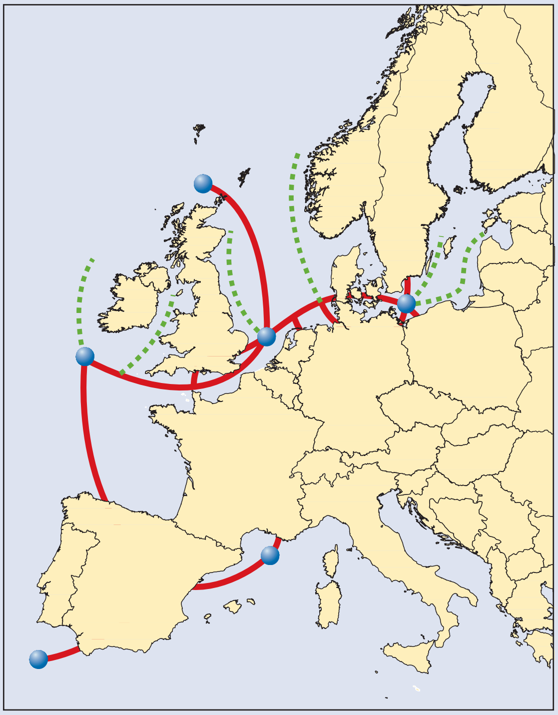
Sources: IEA Wind Task 25; Holttinen et al. (2007)

Figures S.7–S.9 show three examples of offshore grid configurations in the North Sea.

GRID CONNECTION REQUIREMENTS

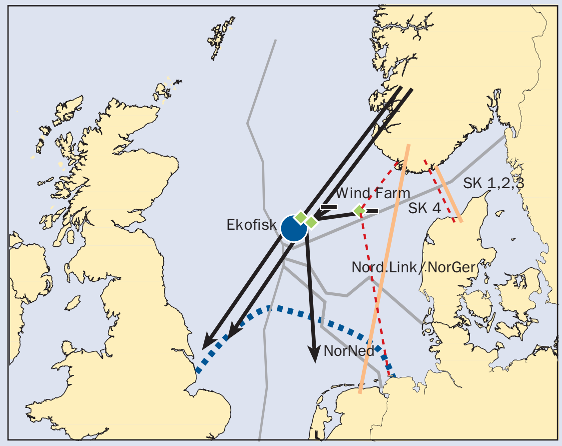
Specific technical requirements within grid codes in terms of tolerance, control of active and reactive power, protective devices, and power quality are changing as penetration increases and wind power assumes additional power plant capabilities, such as active control and the provision of grid support services (Chapter II.5). There may also be a move towards markets for control services, rather than mandatory requirements. In principle, this would make economic sense, as the generator best able to provide the service would be contracted.

Figure S.7: Vision of high voltage 'super grid' to transmit wind power through Europe



Source: Dowling and Hurley (2004)

Figure S.8: Offshore grid proposal by Statnett



Source: Statnett (2008)

As wind energy penetration increases, there is a greater need to develop a harmonised set of grid code requirements, which would require a concerted effort by the wind power industry and system operators.

WIND POWER'S CONTRIBUTION TO SYSTEM ADEQUACY

For low wind energy penetration levels, the relative capacity credit of wind power (that is 'firm' capacity as a fraction of total installed wind power capacity) is close to the average production (load factor) during the period under consideration – usually the time of highest demand. For north European countries, this is typically 25 to 30 per cent onshore and up to 50 per cent offshore.

With increasing penetration levels of wind energy in the system, its relative capacity credit reduces. However, this does not mean, as Chapter II.6 shows, that less conventional capacity can be replaced, but rather that adding a new wind plant to a system with high wind power penetration levels will substitute less than the first wind plants in the system.

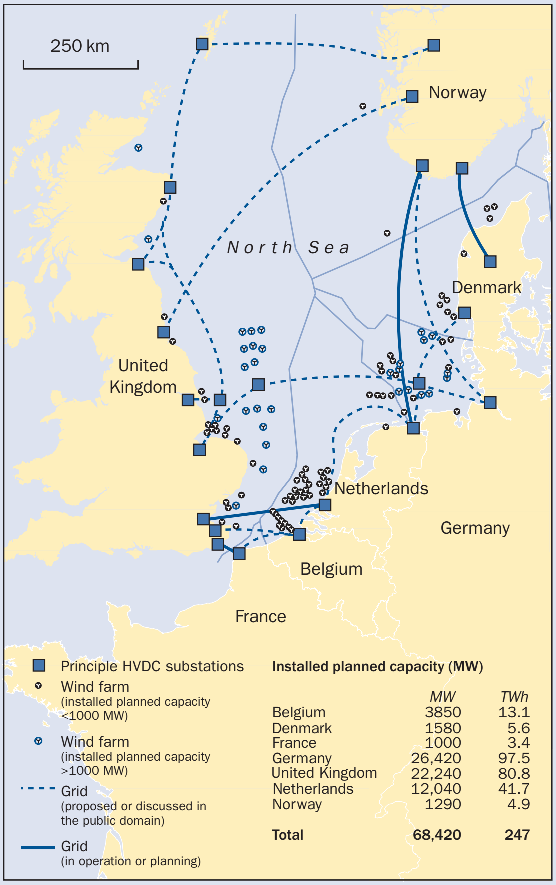
MARKET DESIGN

In the interest of economical wind power integration, changes in market rules throughout Europe are required, so that markets operate faster and on shorter gate closure times (typically three hours ahead or less). This will minimise forecasting uncertainty and last-minute balancing needs. Further substantial economic benefits are expected from the geographical enlargement of market and balancing areas, and from appropriate market rules in cross-border power exchange.

ECONOMICS OF WIND POWER INTEGRATION

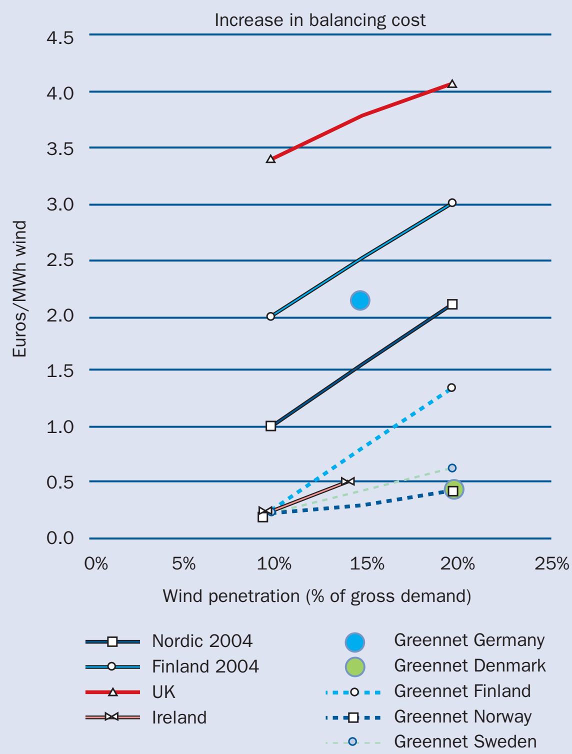
The introduction of significant amounts of wind energy into the power system brings with it a series of economic

Figure S.9: Offshore grid examined in the Greenpeace study



Source: Woyte et al. (2008)

Figure S.10: Estimates for the increase in balancing and operating costs due to wind power



Source: Holttinen et al. (2007)

impacts, both positive and negative. Two main factors determine wind energy integration costs: balancing needs and grid infrastructure (Chapter II.7). The additional balancing cost in a power system arises from the inherent variable nature of wind power, requiring changes for other generators to deal with unpredicted deviations between supply and demand. Evidence from national studies shows that these additional costs represent only a small fraction of the generation costs of wind energy and the overall balancing costs of the power system.

Figure S.10 illustrates the costs from several studies as a function of wind power penetration. Balancing costs increase on a linear basis with wind power penetration, but the absolute values are moderate and always less than €4/MWh at the 20 per cent level (and more often below €2/MWh).

Network upgrade costs arise from the need to connect wind plants and from the extra capacity required to carry the increased power flows in the transmission and distribution networks. Networks also need to be adapted to improve voltage management, and additional interconnection capacity between countries is required to optimally capture the benefits of the continental nature of the wind resource. Any infrastructure improvement fulfilling these needs would provide multiple benefits to the system, and so its cost should not be allocated only to wind power generation.

The cost of modifying power systems with significant amounts of wind energy increases in a quasi linear fashion with wind energy penetration. Identifying an 'economic optimum' is not easy, as costs are accompanied by benefits. Benefits include significant reductions in fossil fuel consumption and cost reductions due to decreased energy dependency, and they are already visible as lower prices in the power exchange markets where large amounts of wind power are offered. From the studies carried out so far, when extrapolating the results to high penetration levels, it is clear that the integration of more than 20 per cent of wind power into the EU power system would be economically beneficial.

Experience and studies provide positive evidence on the feasibility and solutions for integrating the expected wind power capacity in Europe for 2020, 2030 and beyond. Today, the immediate questions mainly relate to the most economic way of dealing with the issues of power system design and operation, electrical network upgrade, connection rules, and electricity market design.

One of the challenges is the creation of appropriate market rules, including incentives to enable power generation and transmission to develop towards being able to accommodate variable output and decentralised generation, notably by becoming more flexible and providing more interconnection capacity. Studies are required at the European level to provide a technical and scientific basis for grid upgrade and market organisation.

Part III: The Economics of Wind Power

Wind power is developing rapidly at both European and global levels. Over the past 15 years, the global installed capacity of wind power has increased from around 2.5 GW in 1992 to more than 94 GW at the end of 2007 – an average annual growth of more than 25 per cent. Due to ongoing improvements in turbine efficiency and higher fuel prices, wind power is increasing in economic competitiveness against conventional power production. And at sites with high wind speeds on land, wind power is considered to be fully commercial today.

ONSHORE WIND POWER

Capital costs of onshore wind energy projects, covered in Chapter III.1, are dominated by the cost of the wind turbine. The total investment cost of an average turbine installed in Europe is around €1.23 million/MW, including all additional costs for foundations, electrical installation and consultancy (2006 prices). The main costs are divided as follows (approximate levels): turbine 76 per cent, grid connection 9 per cent and foundations 7 per cent. Other cost components, such as control systems and land, account for a minor share of the total costs. The total cost per kW of installed wind power capacity differs significantly between countries, from around €1000/kW to €1350/kW.

In recent years, three major trends have dominated the development of grid-connected wind turbines:

1. turbines have become larger and taller;
2. the efficiency of turbine production has increased steadily; and
3. in general, the investment costs per kW have decreased, although there has been a deviation from this trend in the last three to four years.

In 2007, turbines of the MW-class (above 1 MW) represented a market share of more than 95 per cent,

Table S.2: Cost structure of a typical 2 MW wind turbine installed in Europe (2006-€)

	Investment (€1000/MW)	Share (%)
Turbine (ex-works)	928	75.6
Foundations	80	6.5
Electric installation	18	1.5
Grid connection	109	8.9
Control systems	4	0.3
Consultancy	15	1.2
Land	48	3.9
Financial costs	15	1.2
Road	11	0.9
Total	1227	100

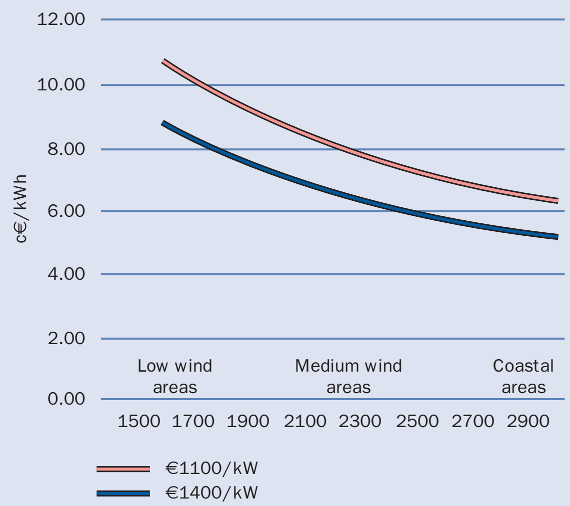
Note: Calculated by the author based on selected data for European wind turbine installations.

Source: Risø DTU

leaving less than 5 per cent for the smaller machines. Within the MW-segment, turbines with capacities of 2.5 MW or above are becoming increasingly important, even for onshore siting. The wind regime at the chosen site, the turbine hub height and the efficiency of production determine the turbine's power production. So just increasing the height of turbines has resulted in higher power production. Similarly, the methods for measuring and evaluating the wind speed at a given site have improved significantly in recent years, and thus improved the siting and economics of new turbines.

Electricity production efficiency, owing to better equipment design, has also improved dramatically. From the late 1980s until 2004, overall investments per unit of swept rotor area decreased by more than 2 per cent per annum. However, in 2006, total investment costs rose by approximately 20 per cent compared to 2004, mainly due to a marked increase in global demand for wind turbines, combined with rising commodity prices and supply constraints. Preliminary data indicates that prices have continued to rise in 2007. At present, production costs of energy for a 2 MW wind turbine range from 5.3 to 6.1 euro cents (c€) per kWh, depending on the wind resource at the chosen site. According to experience curve analyses, the cost range is expected to decline to between 4.3 and 5.5c€/kWh by 2015.

Figure S.11: Calculated costs per kWh of wind generated power as a function of the wind regime at the chosen site (number of full load hours)



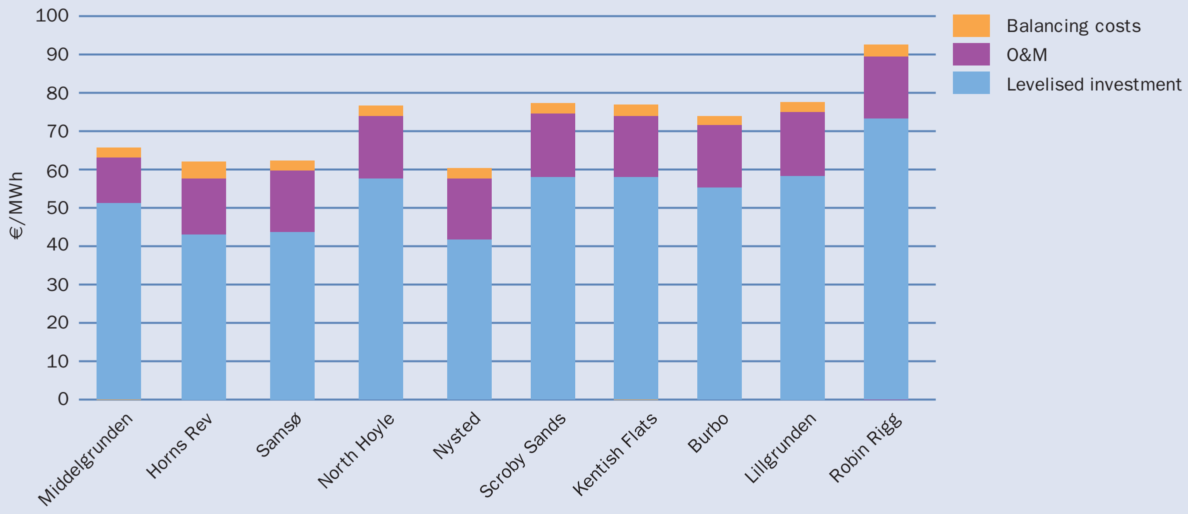
Source: Risø DTU

OFFSHORE DEVELOPMENT

Offshore wind (Chapter III.2) only accounts for around 1 per cent of total installed wind power capacity in the world, and development has taken place mainly around the North Sea and the Baltic Sea. At the end of 2007, there was a capacity of more than 1000 MW located offshore in five countries: Denmark, Ireland, The Netherlands, Sweden and the UK. Most of the capacity has been installed in relatively shallow water (less than 20 m), and no further than 20km from the coast, so as to minimise the costs of foundations and sea cables.

The costs of offshore capacity, like those of onshore turbines, have increased in recent years. On average, investment costs for a new offshore wind farm are

Figure S.12: Calculated production cost for selected offshore wind farms, including balancing costs (2006 prices)



Source: Risø DTU

expected be in the range of €2.0 to €2.2 million/MW for a near-shore, shallow-depth facility. Compared to land-based turbines, the main differences in the cost structure are related to more expensive foundations, the transformer station and sea transmission cables. The cost of offshore-generated electricity ranges from approximately 6–8c€/kWh, mainly due to differences in sea depth, distance from shore and investment costs.

FINANCE

The nature of business in wind energy is changing. Although there are still many small, privately owned projects, a substantial shift towards bigger, utility-owned projects can be observed – this is discussed in Chapter III.3. This change brings new money to the industry and decreases dependence on banks for initial funding. Powerful sponsors are also arriving on the scene. Projects are increasing in size and large-scale offshore activity is taking off; since banks favour big projects, this is a change for the better. If the general economic picture deteriorates, project finance may suffer, but the strong political and environmental support for renewable energy means that wind energy funding is still viewed as a very attractive option.

PRICES AND SUPPORT MECHANISMS

When clustering different types of support mechanism for electricity from renewables (RES-E), a distinction is made between direct and indirect policy instruments (Chapter III.4). Direct policy measures attempt to stimulate the immediate installation of RES-E technologies, whereas indirect instruments focus on improving the long-term framework conditions. As well as regulatory instruments, there are also voluntary approaches for the promotion of RES-E technologies, mainly based on the willingness of consumers to pay premium rates for green electricity. Other important classification criteria include whether policy instruments address price or quantity, and whether they support investment or generation.

When reviewing and evaluating the various RES-E support schemes, it is important to assess the success of the different policy instruments according to the following criteria:

- Effectiveness: Did the RES-E support programmes lead to a significant increase in deployment of capacities from RES-E in relation to the additional potential?
- Economic efficiency: What was the absolute support level compared to the actual generation costs of RES-E generators and what was the trend in support over time?

Regardless of whether a national or an international support system is concerned, a single instrument is usually not enough to stimulate the long-term growth of RES-E.

IMPACT OF WIND POWER ON SPOT POWER PRICES

In a number of countries, wind power is increasing its share of total power production (Chapter III.5). This is particularly noticeable in Denmark, Spain and Germany, where wind power's contribution to total power supply is 21 per cent, 12 per cent and 7 per cent respectively. In these cases, wind power is becoming an important player in the power market and can significantly influence power prices. As wind power has very low marginal cost (due to zero fuel costs), it enters near the bottom of the supply curve. This shifts the curve to the right, resulting in lower power prices, with the extent of the price reduction depending on the price elasticity of the power demand.

In general, when wind power provides a significant share of the power supply, the price of power is likely to be lower during high-wind periods and higher during low-wind periods. A study carried out in Denmark shows that the price of power to consumers (excluding transmission and distribution tariffs, and VAT and other taxes) in 2004 to 2007 would have been approximately 4–12 per cent higher if wind power had not contributed to power production. This means that in 2007, power consumers saved approximately 0.5c€/kWh due to wind power reducing electricity prices. This should be compared to consumer payments to wind power of approximately 0.7c€/kWh as feed-in tariffs. So although the cost of wind power to consumers is still greater than the benefits, a significant reduction in net expenses is certainly achieved due to lower spot prices.

The analysis involves the impacts of wind power on power spot prices being quantified using structural analyses. A reference is fixed, corresponding to a situation with zero contribution from wind power in the power system. A number of levels with increasing contributions from wind power are identified and, relating to the reference, the effect of wind power's power production is calculated. This is illustrated in the left graph of Figure S.13, where the shaded area between the two curves approximates the value of wind power in terms of lower spot power prices.

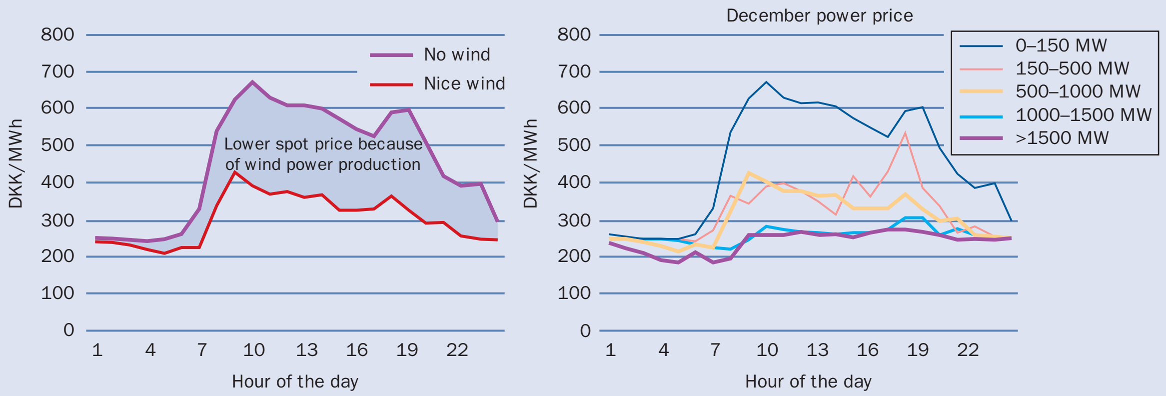
WIND POWER COMPARED TO CONVENTIONAL POWER

In general, the cost of conventional electricity production is determined by four cost components:

1. fuel;
2. CO_2 emissions (as given by the European Trading System for CO_2);
3. operation and maintenance (O&M); and
4. capital, including planning and site work.

Implementing wind power avoids the full fuel and CO_2 costs, as well as a considerable share of conventional power plants' O&M costs. The amount of capital costs avoided depends on the extent to which wind power capacity can displace investments in new conventional power plants; this is linked directly to how wind power plants are integrated into the power system.

Figure S.13: The impact of wind power on the spot power price in the West Denmark power system in December 2005



Source: Risø DTU

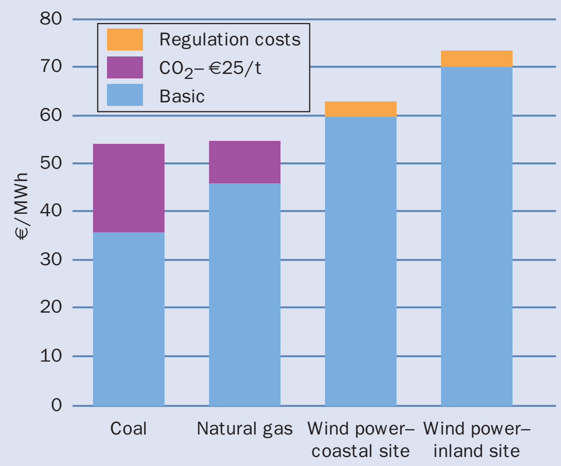
Studies show that the cost of integrating variable wind power is approximately 0.3 to 0.4c€/kWh of wind power generated, even at fairly high levels of wind power penetration (approximately 20 per cent, depending on the nature of the operating system). Figure S.14 shows the results of the reference case, assuming the two conventional power plants are coming on-stream in 2010.

As shown in the reference case, the cost of power generated at conventional power plants is lower than the cost of wind-generated power under the given assumptions of low fuel prices. At a European inland site, wind-generated power is approximately 33–34 per cent more expensive than natural gas- and coal-generated power (Chapter III.6).

This case is based on the *World Energy Outlook* assumptions on fuel prices, including a crude oil price of US$59/barrel in 2010. At present (mid-2008), the crude oil price has reached as high as $147/barrel. Although this oil price is combined with a lower exchange rate for the US dollar, the present price of oil is significantly higher than the forecasted IEA oil price for 2010. Therefore, a sensitivity analysis has been carried out and the results are shown in Figure S.15.

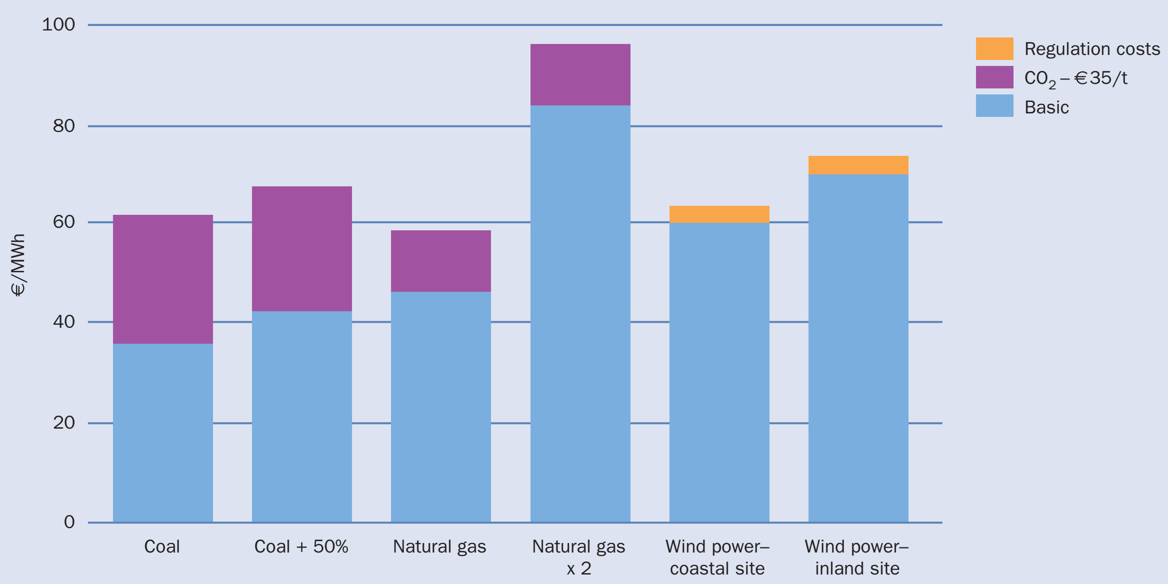
In Figure S.15, the natural gas price is assumed to double compared to the reference (equivalent to an oil price of $118/barrel in 2010), the coal price to increase by 50 per cent and the price of CO_2 to increase

Figure S.14: Costs of generated power comparing conventional plants to wind power, 2010 (constant 2006-€)



Source: Risø DTU

Figure S.15: Sensitivity analysis of costs of generated power comparing conventional plants to wind power, assuming increasing fossil fuel and CO_2 prices, 2010 (constant 2006-€)



Source: Risø DTU

to €35/t from €25/t in 2008. As shown in the figure, the competitiveness of wind-generated power increases significantly, costs at the inland site becoming lower than those of the natural gas plant and only around 10 per cent more expensive than those of the coal-fired plant. On coastal sites wind power produces the cheapest electricity.

EMPLOYMENT

Wind energy companies in the EU currently employ around 108,600 people; when indirect jobs are taken into account, this figure rises to more than 150,000 (Chapter III.7). A significant share of direct wind energy employment (approximately 77 per cent) is located in three countries, Denmark, Germany and Spain, whose combined installed capacity represents 70 per cent of the EU total. However, the sector is less concentrated now than it was in 2003, due to the opening of manufacturing and operation centres in emerging markets and to the fact that many wind-related activities, such as promotion, O&M, engineering and legal services, are now carried out at a local level. Wind turbine and component manufacturers account for most of the jobs (59 per cent).

In addition to the 108,600 direct jobs outlined in the previous section, the European wind energy sector also affects employment in sectors not directly related to wind energy. Approximately 43,000 people were indirectly employed in wind energy in 2007. In total, the EU wind energy sector therefore employed more than 150,000 in 2007. EWEA's analysis concludes that 15.1 jobs are created in the EU for each new MW installed. In addition, 0.4 jobs are created per MW of total installed capacity in operations and maintenance and other activities related to existing installations.

Table S.3: Direct employment from wind energy companies in selected European countries

Country	No of direct jobs
Austria	700
Belgium	2000
Bulgaria	100
Czech Republic	100
Denmark	23,500
Finland	800
France	7000
Germany	38,000
Greece	1800
Hungary	100
Ireland	1500
Italy	2500
The Netherlands	2000
Poland	800
Portugal	800
Spain	20,500
Sweden	2000
United Kingdom	4000
Rest of EU	400
TOTAL	**108,600**

Source: Own estimates, based on EWEA (2008a); ADEME (2008); AEE (2007); DWIA (2008); Federal Ministry of the Environment in Germany, BMU (2008)

Part IV: Industry and Markets

In 2001, the EU passed its Directive on the promotion of electricity produced from renewable energy sources in the internal electricity market. This is still the most significant piece of legislation in the world for the integration of electricity produced by renewable energies, including wind power. This directive contains an indicative target of 21 per cent of final electricity demand in the EU to be covered by renewable energy sources by 2010, and regulates the electricity markets in which they operate. It has been tremendously successful in promoting renewables, particularly wind energy, and is the key factor explaining the global success of the European renewable energy industries and the global leadership position of European wind energy companies.

The gradual implementation of the 2001 Renewable Electricity Directive in the Member States, as well as the unanimous decision made by the European Council at its Spring Summit in March 2007 for a binding 20 per cent share of renewable energy in the EU by 2020, are all steps in the right direction and indicators of increased political commitment. A new directive, based on a European Commission proposal from January 2008, was adopted by the European Parliament and Council in December 2008. It will raise the share of renewable energy in the EU from 8.5 per cent in 2005 to 20 per cent in 2020, which means that more than one-third of the EU's electricity will have to come from renewables in 2020, up from 15 per cent in 2007. It is already clear that wind energy will be the largest contributor to this increase.

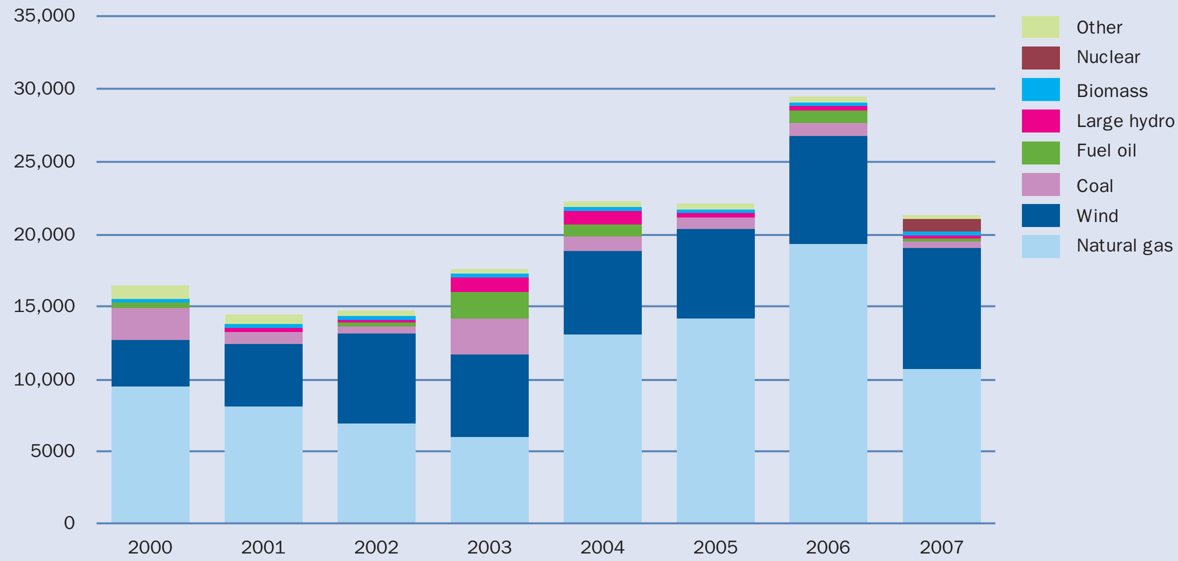
THE EU ENERGY MIX

While thermal generation, totalling over 430 GW, has long served as the backbone of Europe's power production, combined with large hydro and nuclear, Europe is steadily transitioning away from conventional power sources towards renewable energy technologies (Chapter IV.1). Between 2000 and 2007, total EU power capacity increased by 200 GW, reaching 775 GW by the end of 2007. The most notable changes in the mix were the near doubling of gas capacity to 164 GW and wind energy more than quadrupling, from 13 to 57 GW.

WIND ENERGY IN THE EUROPEAN POWER MARKET

The EU is leading the way with policy measures to facilitate the move towards the deployment of renewable energy technologies. With an impressive compound annual growth rate of over 20 per cent in MW installed between 2000 and 2007 (Figure S.16), wind energy has clearly established itself as a relevant power source

Figure S.16: New power capacity, EU, 2000–2007 (in MW)



Source: EWEA/Platts (2008)

in Europe's power generation market. Thirty per cent of all power capacity installed in the EU over the five-year period has been wind power, making it the second largest contributor to installation of EU capacity over the last ten years, after natural gas (55 per cent). In 2007, 40 per cent of annual EU capacity installed was wind power, and wind power increased more than any other power-generating technology in Europe, including natural gas.

Wind power's share has jumped to over 10 per cent of total installed capacity and more than 5 per cent of national electricity demand in five European markets, Germany, Spain, Denmark, Portugal and Ireland, surpassing 10 per cent in both Spain and Denmark.

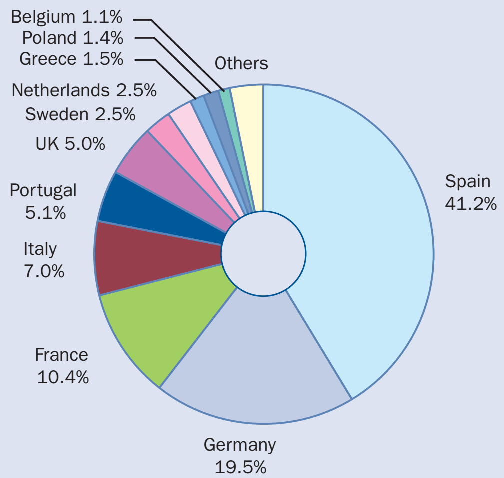
THE CURRENT STATUS OF THE EU WIND ENERGY MARKET

In the EU, installed wind power capacity has increased by an average of 25 per cent annually over the past 11 years, from 4753 MW in 1997 to 56,535 MW in 2007 (Chapter IV.2). In terms of annual installations, the EU market for wind turbines has grown by 19 per cent annually, from 1277 MW in 1997 to 8554 MW in 2007. In 2007, Spain was by far the largest market for wind turbines, followed by Germany, France and Italy. Eight countries – Germany, Spain, Denmark, Italy, France, the UK, Portugal and The Netherlands – now have more than 1000 MW installed. Germany, Spain and Denmark – the three pioneering countries of wind power – are home to 70 per cent of installed wind power capacity in the EU (see Figures S.17 and S.18).

The more than 56,000 MW of total wind power capacity installed in the EU at the end of 2007 will produce 3.7 per cent of the EU-27's electricity demand in an average wind year.

With 1080 MW by the end of 2007, offshore accounted for 1.9 per cent of installed EU capacity and 3.5 per cent of the electricity production from wind power in the EU. The market is still below its 2003

Figure S.17: 2007 Member State market shares of new capacity

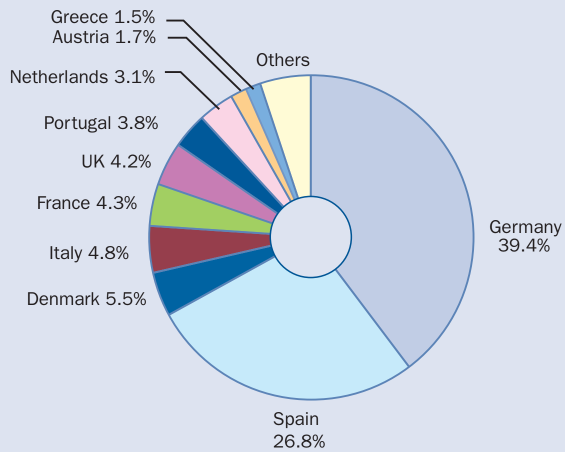


Others

Czech Republic	0.7%	Cyprus	0.0%
Ireland	0.7%	Denmark	0.0%
Estonia	0.3%	Hungary	0.0%
Finland	0.3%	Latvia	0.0%
Bulgaria	0.4%	Luxembourg	0.0%
Austria	0.2%	Malta	0.0%
Lithuania	0.1%	Slovakia	0.0%
Romania	0.1%	Slovenia	0.0%

Source: EWEA (2008a)

Figure S.18: End 2007 Member State market shares of total capacity



Others

Ireland	1.4%	Lithuania	0.1%
Sweden	1.4%	Luxembourg	0.1%
Belgium	0.5%	Latvia	0.0%
Poland	0.5%	Romania	0.0%
Czech Republic	0.2%	Slovakia	0.0%
Finland	0.2%	Cyprus	0.0%
Bulgaria	0.1%	Malta	0.0%
Hungary	0.1%	Slovenia	0.0%
Estonia	0.1%		

Source: EWEA (2008a)

level and development has been slower than previously anticipated.

EUROPEAN WIND INDUSTRY: PLAYERS AND INVESTMENT TRENDS

Wind's spectacular growth as a vehicle for new generation capacity investment has attracted a broad range of players across the industry value chain (Chapter IV.3). From local, site-focused engineering firms to global vertically integrated utilities, all have formed part of wind energy's European growth story.

As the region responsible for pioneering widespread, larger-scale take-up of wind power, Europe hosts the tightest competition for market share, among roughly a dozen suppliers. The European market has seen a highly stable market share distribution, with few major shifts since a round of consolidation among leading suppliers during 2003 and 2004. Between 2004 and 2007, three players averaged over a 15 per cent market share of annual MW added each, followed by four players with a 5–10 per cent share.

Supply chain management represents a key competitive driver in wind turbine supply. The relationships between turbine manufacturers and their component suppliers have become increasingly crucial, and have come under increasing stress in the past three years, as soaring demand has required faster ramp-up times,

Table S.4: Cumulative installations of wind power in the EU and projections for 2010 (in MW)

	Cumulative installations								
Country	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2010**
Austria	77	94	140	415	606	819	965	982	1200
Belgium	13	32	35	68	96	167	194	287	800
Bulgaria					10	10	36	70	200
Cyprus			0	0	0	0	0	0	0
Czech Republic			3	9	17	28	54	116	250
Denmark	2417	2489	2889	3116	3118	3128	3136	3125	4150
Estonia			2	2	6	32	32	58	150
Finland	39	39	43	52	82	82	86	110	220
France	66	93	148	257	390	757	1567	2454	5300
Germany	6113	8754	11,994	14,609	16,629	18,415	20,622	22,247	25,624
Greece	189	272	297	383	473	573	746	871	1500
Hungary			3	3	3	17	61	65	150
Ireland	118	124	137	190	339	496	746	805	1326
Italy	427	682	788	905	1266	1718	2123	2726	4500
Latvia			24	27	27	27	27	27	100
Lithuania			0	0	6	6	48	50	100
Luxembourg	10	15	17	22	35	35	35	35	50
Malta			0	0	0	0	0	0	0
Netherlands	446	486	693	910	1079	1219	1558	1746	3000
Poland			27	63	63	83	153	276	1000
Portugal	100	131	195	296	522	1022	1716	2150	3500
Romania			1	1	1	2	3	8	50
Slovakia			0	3	5	5	5	5	25
Slovenia			0	0	0	0	0	0	25
Spain	2235	3337	4825	6203	8264	10,028	11,623	15,145	20,000
Sweden	231	293	345	399	442	510	571	788	1665
UK	406	474	552	667	904	1332	1962	2389	5115
EU accumulated*	12,887	17,315	23,098	28,491	34,372	40,500	48,031	56,535	80,000

Note: *From 2004 EU-25; from 2007 EU-27.

Source: EWEA (2008a)

larger investments and greater agility to capture value in a rapidly growing sector.

Furthermore, Europe's wind energy value chain is seeing dynamic shifts, as asset ownership is redistributed, growth is sought in maturing markets and players seek to maximise scale on an increasingly pan-European stage. The proliferation of players looking to develop, own or operate wind plants has pushed competition to a new level, underlining the key elements of local market knowledge, technical expertise and financial capacity as crucial to positioning on the value chain.

KEY PLAYER POSITIONING

Europe's shifting distribution of wind power asset ownership clearly illustrates the industry's scaling up and geographic expansion. From an industry concentrated in Denmark and Germany with single, farmer-owned turbines at the end of the 1990s, wind power ownership now includes dozens of multinational players, owning several GWs of installed capacity. Five main blocks of ownership now characterise the structure of the European market:

1. utilities;
2. Europe's largest independent power producers (IPPs);
3. other Spanish IPPs;
4. German investors;
5. other European investors/IPPs.

Over the past five years, the most salient trend has been the increased participation of utilities in the industry. Utility share of total wind power installed increased from 17 per cent in 2002 to 25 per cent in 2007. The biggest jump took place between 2005 and 2006, as the region's top wind utilities saw annual additions of well over 500 MW.

PLANNED FUTURE INVESTMENT

For the 2007 to 2010 timeframe, Europe's top 15 utilities and IPPs in terms of MW owned declared construction pipelines totalling over 18 GW, which translates into well over €25 billion in wind plant investment, based on current cost estimates per MW installed. Overall, the European wind market is expected to grow at a rate of over 9 GW installed annually through to 2010, which translates into annual investments pushing past €10 billion to nearly €16 billion.

The overall European wind power market environment is coming of age with the technology's steady emergence into the overall power market. Although wind has become an integral part of the generation mix, alongside conventional power sources, of markets such as Germany, Spain and Denmark, it continues to face the double challenge of competing against other renewable technologies while proving to be a strong energy choice for large power producers seeking to grow and diversify their portfolios.

THE STATUS OF THE GLOBAL WIND ENERGY MARKETS

In its best year yet, the global wind industry, discussed in Chapter IV.4, installed 20,000 MW in 2007. This development was lead by the US, China and Spain, and it brought the worldwide installed capacity to 94,122 MW. This was an increase of 31 per cent compared with the 2006 market, and represented an overall increase in global installed capacity of about 27 per cent.

The top five countries in terms of installed capacity are Germany (22.3 GW), the US (16.8 GW), Spain (15.1 GW), India (7.8 GW) and China (5.9 GW). In terms of economic value, the global wind market in 2007 was worth about €25 billion (US$37 billion) in new generating equipment, and attracted €34 billion (US$50.2 billion) in total investment.

Europe remains the leading market for wind energy – its new installations represented 43 per cent of the global total and European companies supplied 66 per cent of the world's wind power capacity in 2007.

US AND CHINESE MARKETS CONTINUE TO BOOM

The US reported a record 5244 MW installed in 2007, more than double the 2006 figure, accounting for about 30 per cent of the country's new power-producing capacity in 2007. Overall US wind power generating capacity grew by 45 per cent in 2007, with total installed capacity now standing at 16.8 GW. While wind energy in the EU covered some 4 per cent of 2008 electricity demand, however, US wind farms will generate around 48 billion kWh of electricity in 2008, representing just over 1 per cent of US electricity supply.

China added 3449 MW of wind energy capacity during 2007, representing market growth of 156 per cent over 2006, and now ranks fifth in total installed wind energy capacity, with over 6000 MW at the end of 2007. However, experts estimate that this is just the beginning, and that the real growth in China is still to come. European manufacturers are well positioned to exploit this market opportunity.

ADMINISTRATIVE AND GRID ACCESS BARRIERS

Today, integration of electricity from renewable energy sources into the European electricity market faces multiple barriers. Chapter IV.5 takes a developer's point of view and observes the barriers occurring during the process of acquiring building permits, spatial planning licences and grid access, using the example of four EU Member States.

Barriers are encountered if the procedures with which a project developer has to comply are not set out in a coherent manner; these include a lack of transparency and excessive administrative requirements. Every European Member State faces such barriers, but their impact on the deployment of renewable energy differs for each country. Barriers at the administrative, social and financial levels, as well as in relation to grid connection, are a serious obstacle to investment and the competitiveness of wind energy in the European and global markets.

Part V: Environment

Not all energy sources have the same negative environmental effects or natural resources depletion capability. Fossil energies exhaust natural resources and are mostly responsible for environmental impacts. On the other hand, renewable energies in general, and wind energy in particular, produce few environmental impacts, and these are significantly lower than those produced by conventional energies.

ENVIRONMENTAL BENEFITS

Chapter V.1 describes the life-cycle assessment (LCA) methodology for emissions and environmental impact assessments and, based on relevant European studies, shows the emissions and environmental impacts derived from the electricity production of onshore and offshore wind farms throughout their life cycles. The avoided emissions and environmental impacts from wind electricity compared to the other fossil electricity generation technologies are also examined.

ENVIRONMENTAL IMPACTS

Although the environmental impacts of wind energy are much lower in intensity than those created by conventional energies, they still have to be assessed. The possible negative influences on fauna and nearby populations have been analysed for both onshore and offshore schemes. Specific environmental impacts, such

as those on landscape, noise, bird and marine organism populations, and electromagnetic interference, are examined in Chapter V.2.

Wind energy has a key role to play in combating climate change by reducing CO_2 emissions from power generation. The emergence of international carbon markets, which were spurred by the flexible mechanisms introduced by the Kyoto Protocol, as well as improved regional emissions trading schemes, such as the EU Emissions Trading System (ETS), could provide an additional incentive for the development and deployment of renewable energy technologies, specifically wind energy.

POLICY MEASURES TO COMBAT CLIMATE CHANGE

Wind energy has the potential to make dramatic reductions in CO_2 emissions from the power sector. Chapter V.3 gives an overview of the development of the international carbon markets, assesses the impact of the Clean Development Mechanism and Joint Implementation on wind energy, and outlines the path towards a post-2012 climate regime. It also gives an outline of the EU ETS, discussing the performance to date, the allocation method and proposals for the post-2012 period.

EXTERNALITIES OF WIND COMPARED TO OTHER TECHNOLOGIES

The electricity markets do not currently take account of external effects and the costs of pollution. Therefore it is important to identify the external effects of different electricity generation technologies and calculate the related external costs. External costs can then be compared with the internal costs of electricity, and competing energy systems, such as conventional electricity generation technologies, can be compared with wind energy (Chapter V.4).

Science began to study the external costs of electricity generation in the late 1980s, notably with the Externalities of Energy study (ExternE), which attempted to develop a consistent methodology to assess the externalities of electricity generation technologies. Work and methodologies on the ExternE project are updated on a regular basis. This project values the external costs of wind energy at less than 0.26c€/kWh, with those of conventional (fossil fuel-based) electricity generation being significantly higher.

In Chapters V.4 and V.5, *Wind Energy – The Facts* presents the results of empirical analyses of the emissions and external costs avoided by the replacement of conventional fossil fuel-based electricity generation by wind energy in each of the EU27 Member States in 2007, 2020 and 2030. Wind energy avoided external costs of more than €10 billion in 2007, and this figure is expected to increase as penetration of wind energy increases over the coming decades (Table S.5).

Table S.5: Avoided external energy costs

	2007	2020 (estimated)	2030 (estimated)
Wind energy's contribution to avoided external costs (€ billion, 2007 prices)	10.2	32.9	69.2

Note: A precondition for full implementation of the environmental benefits estimated for 2020 and 2030 is continuous adaptation of financial support instruments and the removal of barriers to market integration of wind energy.

SOCIAL ACCEPTANCE OF WIND ENERGY AND WIND FARMS

Experience with wind energy in the EU shows that social acceptance is crucial for the successful development of wind energy (Chapter V.6). Social research on wind energy has focused on three main points:

1. assessment of the levels of public support for wind energy (public acceptance);
2. identification of and understanding the social response at the local level (community acceptance); and
3. analysis of the key issues involved in social acceptance by key stakeholders and policymakers (stakeholder acceptance).

The way in which wind farms are developed and managed, as well as the way in which the public engages with them, may be more important in shaping public reactions to new projects than the purely physical or technical characteristics of the technology. Such factors significantly affect the relationships between hosting communities, developers and the authorities. There are no fixed rules for the management of social acceptance on technological matters, but proper consideration of this wide range of issues may help promoters and authorities learn from past experiences and find mechanisms to maintain and expand public engagement in wind development.

Part VI: Scenarios and Targets

The European Commission's 1997 White Paper on renewable sources of energy set the goal of doubling the share of renewable energy in the EU's energy mix from 6 to 12 per cent by 2010. It included a target of 40,000 MW of wind power in the EU by 2010, producing 80 TWh of electricity and saving 72 million tonnes (Mt) of CO_2 emissions per year. The 40,000 MW target was reached in 2005.

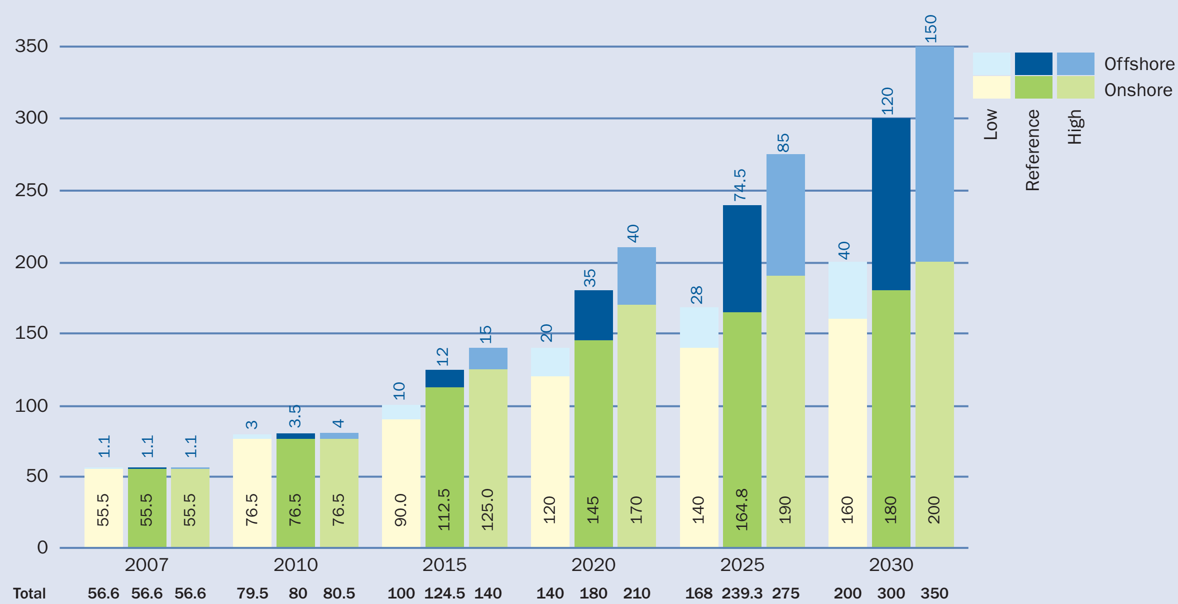
The 40,000 MW goal from the European Commission's White Paper formed EWEA's target in 1997, but three years later, due to the strong developments in the German, Spanish and Danish markets for wind turbines, EWEA increased its target by 50 per cent, to 60,000 MW by 2010 and 150,000 MW by 2020 (Chapters VI.1 and VI.2). In 2003, EWEA once again increased its target, this time by 25 per cent to 75,000 MW by 2010 and 180,000 MW by 2020. Due to the expansion of the EU with 12 new Member States, EWEA increased its reference scenario for 2010 to 80,000 MW, while maintaining its 2020 target of 180,000 MW and setting a target of 300,000 MW by 2030 (Figure S.19).

If the reference scenario is reached, wind power production will increase to 177 TWh in 2010, 477 TWh in 2020 and 935 TWh in 2030 (Chapter VI.3). The European Commission's baseline scenario assumes an increase in electricity demand of 33 per cent between 2005 and 2030 (4408 TWh). Assuming that EU electricity demand develops as projected by the European Commission, wind power's share of EU electricity consumption will reach 5 per cent in 2010, 11.7 per cent in 2020 and 21.2 per cent in 2030.

If political ambitions to increase energy efficiency are fulfilled, moreover, wind power's share of future electricity demand will be greater than the baseline scenario. In 2006, the European Commission released new scenarios to 2030 on energy efficiency and renewables. If EU electricity demand develops as projected in the European Commission's 'combined high renewables and efficiency' (RE&Eff) case, wind energy's share of electricity demand will reach 5.2 per cent in 2010, 14.3 per cent in 2020 and 28.2 per cent in 2030 (see Table S.6).

Since 1996, the European Commission has changed its baseline scenario five times. Over the 12-year period, targets for wind energy in 2010 and 2020 have been increased almost tenfold, from 8000 MW to 71,000 MW (2010) and from 12,000 MW to 120,000 MW (2020) in the European Commission's latest baseline scenario from 2008.

Figure S.19: EWEA's three wind power scenarios (in GW)



Source: EWEA (2008a)

Somewhat surprising, the baseline scenario from 2008 gives significantly lower figures for wind energy than the baseline scenario from 2006. The 71,000 MW projection for 2010 implies that the wind energy market in Europe will decrease by approximately 50 per cent over the next three years with respect to the present market. In light of the current market achievements, growth trends and independent market analyses, the European Commission's baseline scenario seems out of touch with current reality and clearly underestimates the sector's prospects in the longer term.

Table S.6: Wind power's share of EU electricity demand

	2000	2007	2010	2020	2030
Wind power production (TWh)	23	119	177	477	935
Reference electricity demand (TWh)*	2577	3243	3568	4078	4408
RE&Eff case electricity demand (TWh)*	2577	3243	3383	3345	3322
Wind energy share (reference)	0.9%	3.7%	5.0%	11.7%	21.2%
Wind energy share (RE&Eff case)	0.9%	3.7%	5.2%	14.3%	28.2%

*Sources: Eurelectric, EWEA and European Commission

Both the European Commission and IEA's baseline scenarios for wind energy assume that market growth will slow significantly – the European Commission by as much as 50 per cent (compared to the EWEA scenario), to reach its 71 GW target for 2010. Their advanced scenarios, however, are in line with EWEA's target for 2010, while the European Commission's 2006 scenario even exceeds EWEA's 180 GW target for 2020.

Turbine prices have increased since 2005; however, one of the significant advantages of wind power is that

Table S.7: Savings (in billions of €) made depending on the price of fuel and CO_2 (per tonne)

Totals (fuel prices equivalent to oil at \$90; CO_2 €25)	2008–2010	2011–2020	2021–2030	2008–2020	2008–2030
Investment	31,062	120,529	187,308	151,591	338,899
Avoided CO_2 cost	21,014	113,890	186,882	134,904	321,786
Avoided fuel cost	51,165	277,296	455,017	328,462	783,479
Totals (fuel prices equivalent to oil at \$50; CO_2 €10)	**2008–2010**	**2011–2020**	**2021–2030**	**2008–2020**	**2008–2030**
Investment	31,062	120,529	187,308	151,591	338,899
Avoided CO_2 cost	8406	45,556	74,753	53,962	128,714
Avoided fuel cost	30,456	165,057	270,843	195,513	466,356
Totals (fuel prices equivalent to oil at \$120; CO_2 €40)	**2008–2010**	**2011–2020**	**2021–2030**	**2008–2020**	**2008–2030**
Investment	31,062	120,529	187,308	151,591	338,899
Avoided CO_2 cost	33,623	182,223	299,011	215,846	514,857
Avoided fuel cost	67,002	363,126	595,856	430,128	1,025,984

Source: EWEA (2008)

the fuel is free. Therefore the total cost of producing wind energy throughout the 20- to 25-year lifetime of a wind turbine can be predicted with great accuracy. Neither the future prices of coal, oil or gas nor the price of carbon will affect the cost of wind power production. This, as Chapter VI.4 points out, is probably wind energy's most significant competitive advantage in the global energy market.

Cumulative investments in wind energy over the three decades from 2000 to 2030 will total €390 billion. According to EWEA's reference scenario, approximately €340 billion will be invested in wind energy in the EU-27 between 2008 and 2030.

As can be seen from Table S.7, changing the CO_2 and the fuel price assumptions has a dramatic impact on the resulting fuel and CO_2 costs that are avoided by installing wind power capacity. With low CO_2 prices (€10/t) and fuel prices (equivalent of \$50/barrel of oil) throughout the period, the wind power investments over the next 23 years avoid €466 billion instead of €783 billion in fuel and CO_2 costs. With high prices for CO_2 (€40/t) and fuel (equivalent to \$120/barrel of oil), wind power would avoid fuel and CO_2 costs equal to more than €1 trillion over the three decades from 2000 to 2030.

Table S.7 shows the different savings made depending on the price of oil (per barrel) and CO_2 (per tonne).

The Global Wind Energy Council (GWEC) predicts that the global market for wind turbines will grow by over 155 per cent from 94 GW in 2007 to reach 240.3 GW of total installed capacity by 2012 (Chapter VI.5). In particular, the US and Chinese markets are expected to expand dramatically.

Depending on the increase in demand, wind power could cover 11.5 to 12.7 per cent of global electricity consumption in 2020, according to GWEC, and as much as 20.2 to 24.9 per cent – in other words between a fifth and a quarter of the world's electricity needs – in 2030 (Chapter VI.6).