WIND ENERGY - THE FACTS

PART VI

SCENARIOS AND TARGETS

Acknowledgements

Part VI was compiled by Arthouros Zervos of the National Technical University of Athens, Greece (www.ntua.gr), and Christian Kjaer of EWEA.

PART VI INTRODUCTION

In December 2008, the EU agreed to a 20 per cent binding target for renewable energy for 2020. The agreement means that more than one third of the EU's electricity will come from renewable energy in 2020, up from 15 per cent in 2005. To achieve this, the European Commission has calculated that 12 per cent of EU electricity should come from wind power.

Part VI takes different scenarios and targets for wind energy development from the industry, the International Energy Agency (IEA) and the European Commission and compares them. It makes sense of what they mean in financial, environmental, industrial and political terms, both for the EU and globally.

It explains how factors such as energy efficiency, offshore development and political decision-making will have a significant effect on whether current scenarios for total installed capacity and the percentage of electricity coming from wind power hold true. Moreover, fluctuating oil prices affect avoided fuel costs, and carbon prices determine how much wind energy saves in avoided CO_2.

These uncertainties have made it necessary for the European Wind Energy Association (EWEA), the Global Wind Energy Council (GWEC), the European Commission and the IEA to develop differing scenarios for wind energy development to 2020 and 2030.

Part VI of this volume uses a wide variety of graphs and charts to depict and compare the various possibilities. It looks at what these translate into in terms of electricity production from wind. It discusses the potential evolution of the cost of installed wind power capacity and of the expenditure avoided thanks to wind's free fuel, again comparing EWEA, European Commission and IEA scenarios.

Overall, the chapters in this final part demonstrate through detailed analysis the relatively indefinite, albeit bright, future of wind energy in Europe and worldwide. Wind energy is set to continue its impressive growth and become an ever more mainstream power source. Yet specific scenarios will remain open to conjecture and modification due to the vast quantity of unknowns to which wind energy development is subject.

Overview and Assessment of Existing Scenarios

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 per cent 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. The 40,000 MW target was reached in 2005. Another target of the White Paper was to increase the share of electricity from renewable energy sources from 337 TWh in 1995 to 675 TWh in 2010. By the end of 2007, there was 56,535 MW of wind power capacity installed in the EU, producing 119 TWh of electricity and saving approximately 90 Mt of CO_2 annually.

The European Commission's White Paper was followed by Directive 2001/77/EC on the promotion of electricity from renewable energy sources. This important piece of legislation for renewables has led the 27 Member States to develop frameworks for investments in renewable energy. These frameworks had to include financial instruments and reduce both administrative and grid access barriers.

The directive set national indicative targets for the contribution of electricity from renewables as a percentage of gross electricity consumption. The overall goal set out in the directive was to increase the share of electricity coming from renewables from 14 per cent in 1997 to 22 per cent (21 per cent after enlargement) in 2010. With the latest EU directive for the promotion of renewables, more than one third of the EU's electricity will come from renewable energy in 2020.

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). 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 has now increased its prediction 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.

VI.1 SCENARIOS FOR THE EU-27

While EWEA is confident that its predictions for wind power capacity in the EU to 2010 will be met, there is uncertainty about the projections for 2020 and 2030. The likelihood of a significant market for offshore wind power has been pushed beyond the 2010 timeframe, predominantly as a result of strong onshore wind market growth in the US, China and India in recent years. Much also depends on the future EU regulatory framework for the period after 2010.

In 2008, EWEA published three scenarios – low, reference and high – for the development of wind energy up to 2030.[1]

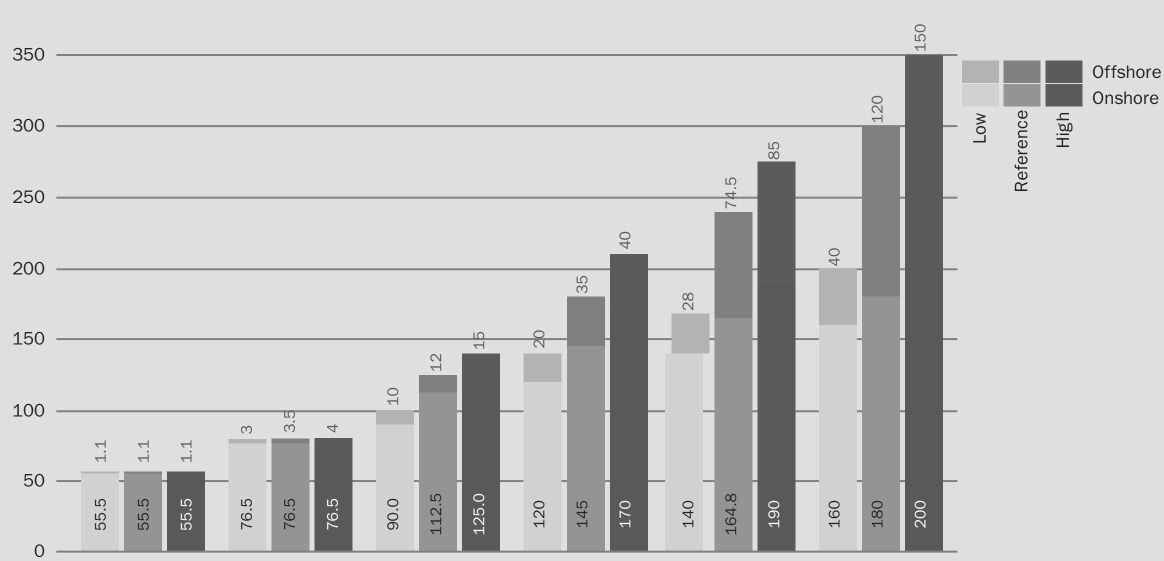
Much of the development over the coming two decades will depend on the evolution of the offshore market, over which there is currently some uncertainty. In December 2007, the European Commission announced a Communication on Offshore Wind Energy. As mentioned, EWEA's reference scenario assumes 180 GW of installed wind energy capacity in 2020 and 300 GW in 2030. The EU will have 350 GW (including 150 GW offshore) in the high scenario and 200 GW (including 40 GW offshore) in the low scenario in 2030.

The 56.5 GW of installed capacity in the EU-27 by the end of 2007 produces, in a normal wind year, 119 TWh of electricity, enough to meet 3.7 per cent of EU electricity demand.

In terms of wind power's electricity production and its share of total EU power demand, there are large differences between the three scenarios. Much depends on whether total electricity demand in the EU increases according to the European Commission's business-as-usual (BAU) scenario or stabilises according to its energy efficiency (EFF) scenario.

As can be seen from Table VI.1.1, wind power will produce between 176 TWh (low scenario) and 179 TWh (high scenario) in 2010, between 361 TWh and 556 TWh in 2020, and between 571 TWh and 1104 TWh in 2030.

Figure VI.1.1: EWEA's three wind power scenarios (in GW)



Total	**56.6**	**56.6**	**56.6**	**79.5**	**80**	**80.5**	**100**	**124.5**	**140**	**140**	**180**	**210**	**168**	**239.3**	**275**	**200**	**300**	**350**

Source: EWEA (2008a)

Table VI.1.2 shows that in EWEA's reference scenario, wind energy meets between 5.0 per cent (BAU) and 5.2 per cent (EFF) of EU electricity demand in 2010, between 11.6 per cent and 14.3 per cent in 2020, and between 20.8 per cent and 28.2 per cent in 2030, depending on how overall electricity consumption develops in the EU between now and 2030.

The calculations in the following sections are based on EWEA's reference scenario and the European Commission's BAU scenario for electricity consumption.

It is assumed that the average capacity factor of all wind turbines in the EU will increase from 24 per cent in 2007 to 25.3 per cent in 2010 and 30.3 per cent in 2020. The increase will be due to better design, exploiting the resources in more windy areas of Europe, technology improvements and a larger share of offshore wind. In Germany, average capacity factors will only start increasing if older turbines start being replaced and offshore wind power takes off. It should be noted that for a technology that makes use of a free resource, a high capacity factor is not a goal in itself. It is not technically problematic to increase capacity factors, but doing so affects grid integration, modelling and generation costs.

Table VI.1.1: Electricity production (in TWh) for EWEA's three scenarios

	Low			Reference			High		
	Onshore	Offshore	Total	Onshore	Offshore	Total	Onshore	Offshore	Total
2007	115	4	119	115	4	119	115	4	119
2010	165	11	176	165	13	177	165	15	179
2015	204	37	241	255	45	299	283	56	339
2020	285	76	361	344	133	477	403	152	556
2025	350	109	459	412	289	701	475	330	805
2030	415	156	571	467	469	935	519	586	1,104

Table VI.1.2: Share of EU electricity demand from wind power, for EWEA's three scenarios and the two EC projections for electricity demand

	Low			Reference			High		
	Onshore	Offshore	Total	Onshore	Offshore	Total	Onshore	Offshore	Total
2007 share EFF				3.5%	0.1%	3.7%			
2007 share BAU				3.5%	0.1%	3.7%			
2010 share EFF	4.9%	0.3%	5.2%	4.9%	0.4%	5.2%	4.9%	0.4%	5.3%
2010 share BAU	4.6%	0.3%	4.9%	4.6%	0.4%	5.0%	4.6%	0.4%	5.0%
2020 share EFF	8.5%	2.3%	10.8%	10.3%	4.0%	14.3%	12.1%	4.6%	16.6%
2020 share BAU	6.9%	1.9%	8.8%	8.4%	3.2%	11.6%	9.8%	3.7%	13.5%
2030 share EFF	12.5%	4.7%	17.2%	14.1%	14.1%	28.2%	15.6%	17.6%	33.2%
2030 share BAU	9.2%	3.5%	12.7%	10.4%	10.4%	20.8%	11.5%	13.0%	24.5%

VI.2 PROJECTING TARGETS FOR THE EU-27 UP TO 2030

Targets for 2010

EWEA's target for 2010 assumes that approximately 23.5 GW of wind energy will be installed in 2008–2010. The Danish wind energy consultancy BTM Consult is more optimistic than EWEA, and foresees a cumulative installed capacity of 91.5 GW by the end of 2010. The main growth markets it highlights are Portugal, France and the UK.

By the end of 2007, 1.9 per cent of wind capacity in the EU was in offshore installations, producing 3.4 per cent of total wind power in Europe. In 2010, EWEA expects 4.4 per cent of total capacity and 16 per cent of the annual market to be covered by offshore wind. Offshore wind power's share of total EU wind energy production will increase to 7 per cent by 2010.

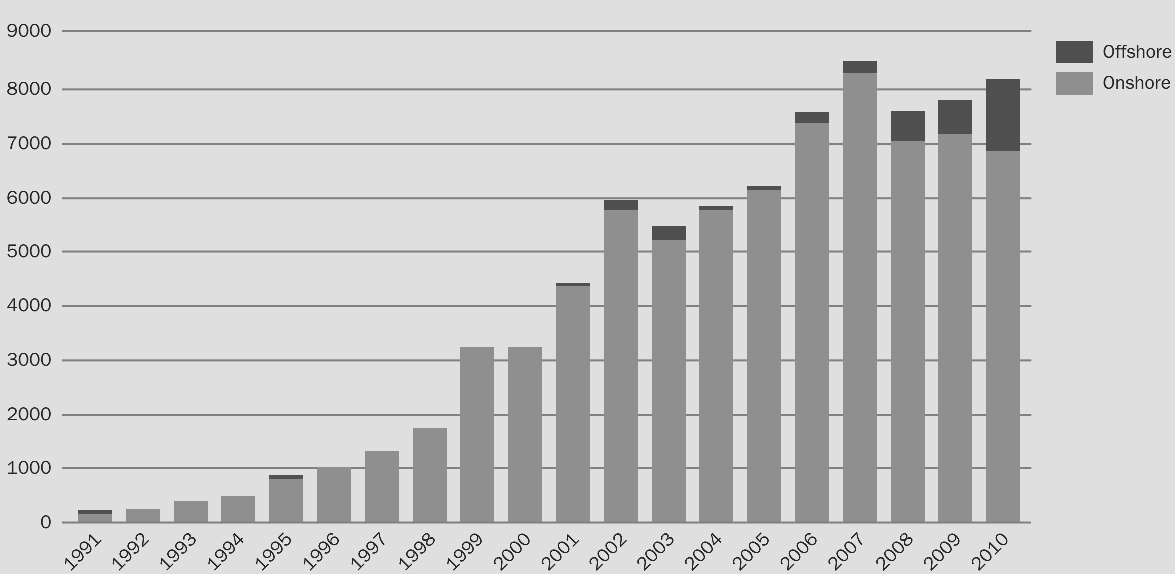
The 56.5 GW of installed capacity in the EU-27 by the end of 2007 will, in a normal wind year, produce 119 TWh of electricity, enough to meet 3.7 per cent of EU electricity demand. The capacity installed by the end of 2010 will produce 177 TWh in a normal wind year, equal to 5 per cent of demand in 2010 (5.7 per cent of 2006 demand). With efficiency measures, wind power's share would cover 5.2 per cent of electricity demand in 2010.

Germany is projected to reach 25 GW and Spain 20 GW of wind capacity in 2010. France, the UK, Italy, Portugal and The Netherlands constitute a second wave of stable markets and will install 42 per cent of new EU capacity over the 2008–2010 period.

For 2008, the annual EU market is expected to fall back to its 2006 level and then increase slightly up to 2010, when it should reach 8200 MW. The forecast assumes that the negotiations on a new EU Renewable Energy Directive and the subsequent development of national action plans in the Member States could cause some legal uncertainty until implemented.

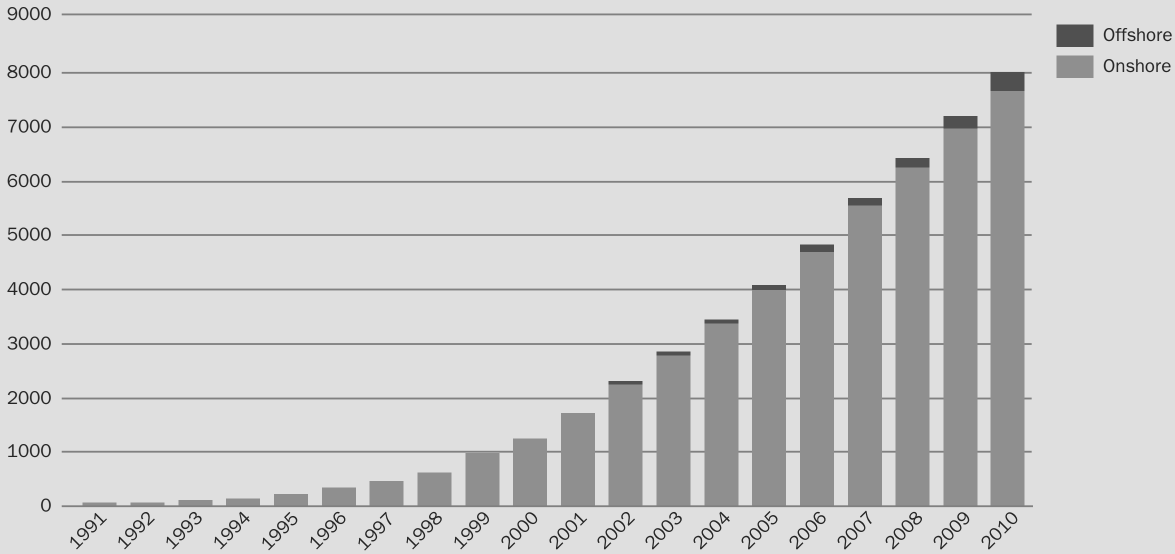
In the three-year period from 2007 to 2010, EWEA forecasts that 23.5 GW of wind energy capacity, including 2.4 GW offshore, will be installed. This will equate to total investments of €31 billion.

Figure VI.2.1: Annual wind power capacity in the EU, 1991–2010 (in MW)



Source: EWEA (2008a)

Figure VI.2.2: Cumulative capacity in the EU, 1991–2010 (in MW)



Source: EWEA (2008a)

Over the same three-year period, Germany and Spain's share of the European annual market will be 34 per cent, compared to 60 per cent in 2007 and 80 per cent in 2002, confirming the healthy trend towards less reliance on the first-mover markets. The largest markets in the period are expected to be Spain (20.7 per cent), Germany (14.4 per cent), France (12.1 per cent), the UK (11.6 per cent) and Italy (7.6 per cent). The total includes an additional 102 MW of capacity that should be built to replace turbines installed prior to 1991.

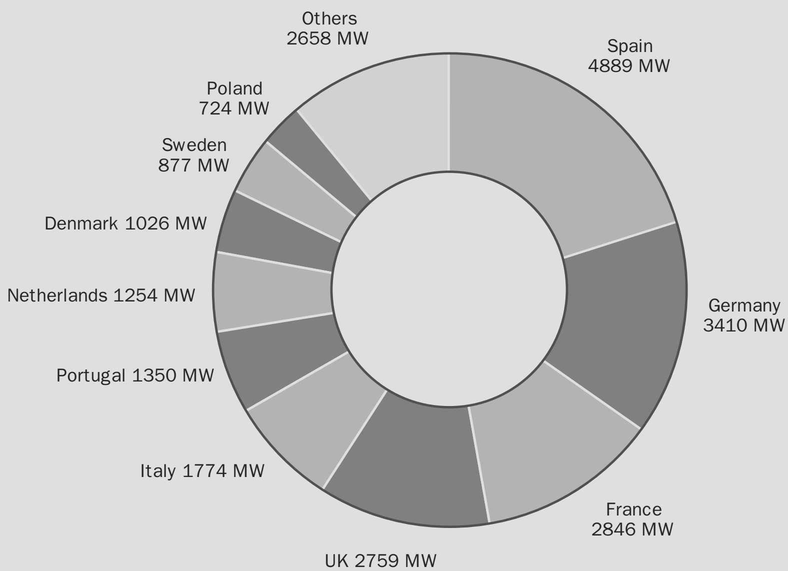
Targets for 2020

On 9 March 2007, the European Heads of State agreed on a binding target of 20 per cent renewable energy by 2020. The 2005 share of renewable energy was approximately 7 per cent of primary energy and 8.5 per cent of final consumption. In January 2008, the European Commission proposed a new legal framework for renewables in the EU, including a distribution of the 20 per cent target between Member States and national action plans containing sectoral targets for electricity, heating and cooling, and transport.

To meet the 20 per cent target for renewable energy, the European Commission expects 34 per cent[2] of electricity to come from renewable energy sources by 2020 (43 per cent of electricity under a 'least cost' scenario[3]) and believes that 'wind could contribute 12 per cent of EU electricity by 2020'.

In 2005 (the reference year of the proposed directive), approximately 15 per cent of EU electricity demand was covered by renewables, including around 10 per cent from large hydro and about 2.1 per cent from wind energy. Excluding large hydropower, for which the realisable European potential has already been reached, and assuming that electricity demand does not increase, the share of renewable electricity in the EU will need to grow fivefold – from approximately 5 per cent to 25 per cent – to reach the electricity target.

Figure VI.2.3: New wind power capacity in the EU, 2008–2010 (total 23,567 MW)

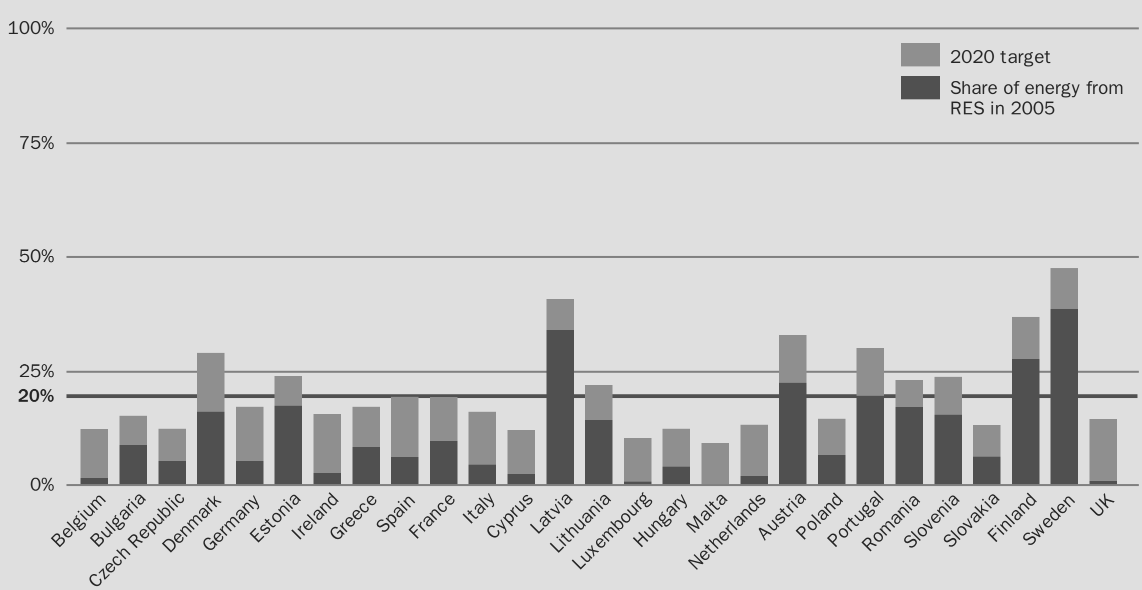


Others

Greece	629 MW
Ireland	521 MW
Belgium	513 MW
Austria	218 MW
Czech Republic	134 MW
Bulgaria	130 MW
Finland	110 MW
Estonia	92 MW
Hungary	85 MW
Latvia	73 MW
Lithuania	50 MW
Romania	42 MW
Slovenia	25 MW
Slovakia	20 MW
Luxembourg	15 MW
Malta	0 MW
Cyprus	0 MW

Source: EWEA (2008a)

Figure VI.2.4: National overall targets for the share of RES in final energy consumption, 2020



Source: European Commission draft proposal for a Directive on the promotion of the use of energy from renewable sources, EWEA (2008a)

Table VI.2.1: Targets for RES, electricity from RES and wind energy for 2020

	2005	2020
Renewable energy sources (RES)	8.5%	20%
Electricity from RES	15%	34%
Wind energy	2.1%	12–14%
Offshore wind energy	0	3.2–4%

With increased demand, renewable electricity other than large hydropower will need to grow even more.

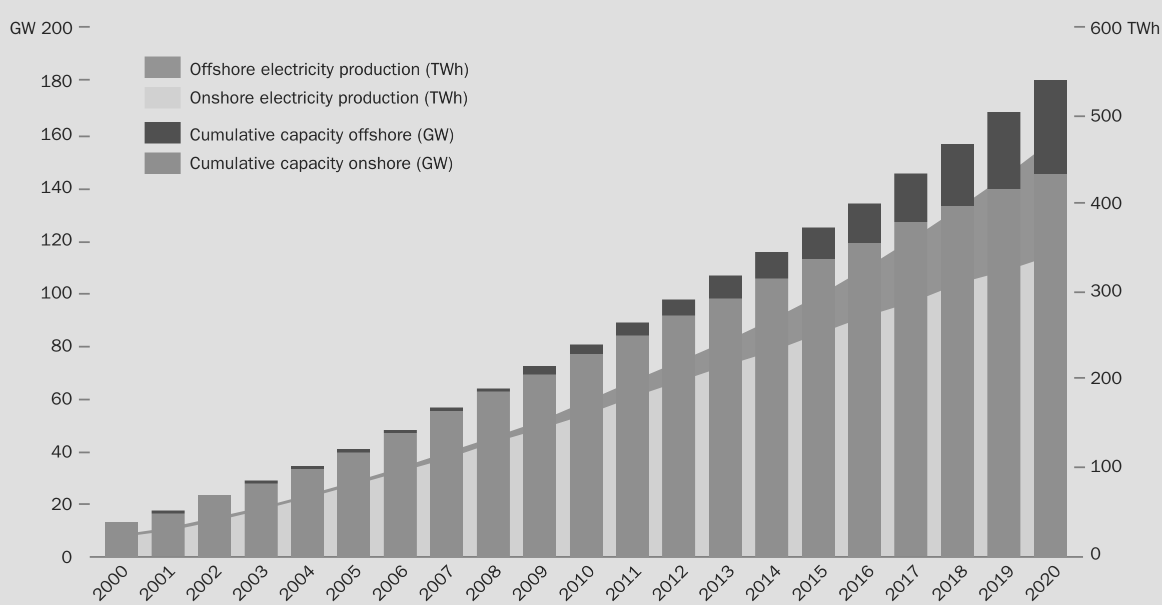
EWEA maintains the target it set in 2003 of 180 GW by 2020, including 35 GW offshore in its reference scenario. That would require the installation of 123.5 GW of wind power capacity, including 34 GW offshore, in the 13-year period from 2008 to 2020; 16.4 GW of capacity is expected to be replaced in the period.

The 180 GW would produce 477 TWh of electricity in 2020, equal to between 11.6 per cent and 14.3 per cent of EU electricity consumption, depending on the development in demand for power. Twenty-eight per cent of the wind energy would be produced offshore in 2020.

Between 2011 and 2020, the annual onshore market for wind turbines will grow steadily from around 7 GW per year to around 10 GW per year. The offshore market will increase from 1.2 GW in 2011 to reach 6.8 GW in 2020. Throughout the period of the reference scenario, the onshore wind power market exceeds the offshore market in the EU.

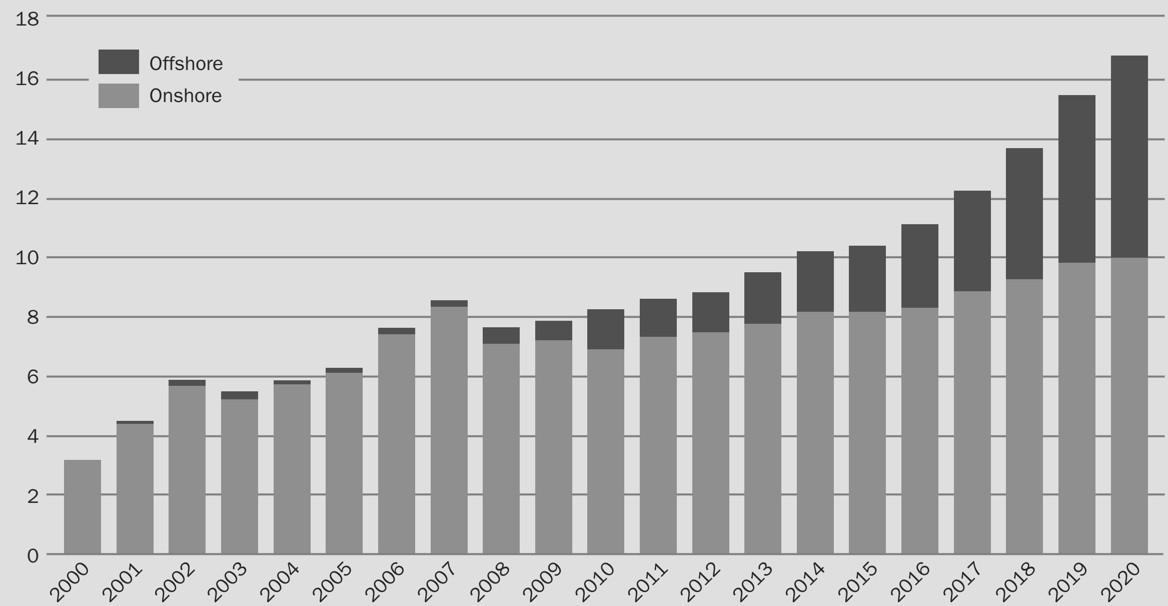
A precondition for reaching the EWEA target of 180 GW is that the upcoming Renewable Energy Directive establishes stable and predictable frameworks in the Member States for investors. Much also depends on the European Commission's Communication on Offshore Wind Energy (scheduled for the second half of 2008) and a subsequent adoption of a European policy for offshore wind power in the EU.

Figure VI.2.5: Electricity from wind to 2020



Source: EWEA (2008a)

Figure VI.2.6: Wind energy annual installations, 2000–2020 (in GW)



Source: EWEA (2008a)

Targets for 2030

In the EWEA reference scenario, 300 GW of wind power will be operating in the EU in 2030, including 120 GW (40 per cent) of offshore wind power. In the decade from 2021 to 2030, 187 GW will be installed. Of this, 67 GW will be needed to replace decommissioned capacity, predominantly onshore. Onshore will represent 54 per cent (101 GW) of the capacity installed during that decade and the onshore market will remain larger than the offshore market throughout, although the gap narrows towards the end. By 2030, the annual onshore market will be 9.9 GW and the offshore market 9.6 GW, representing investments of €19 billion. In 2025, the offshore market is expected to reach the size of the 2008 onshore market (8.5 GW).

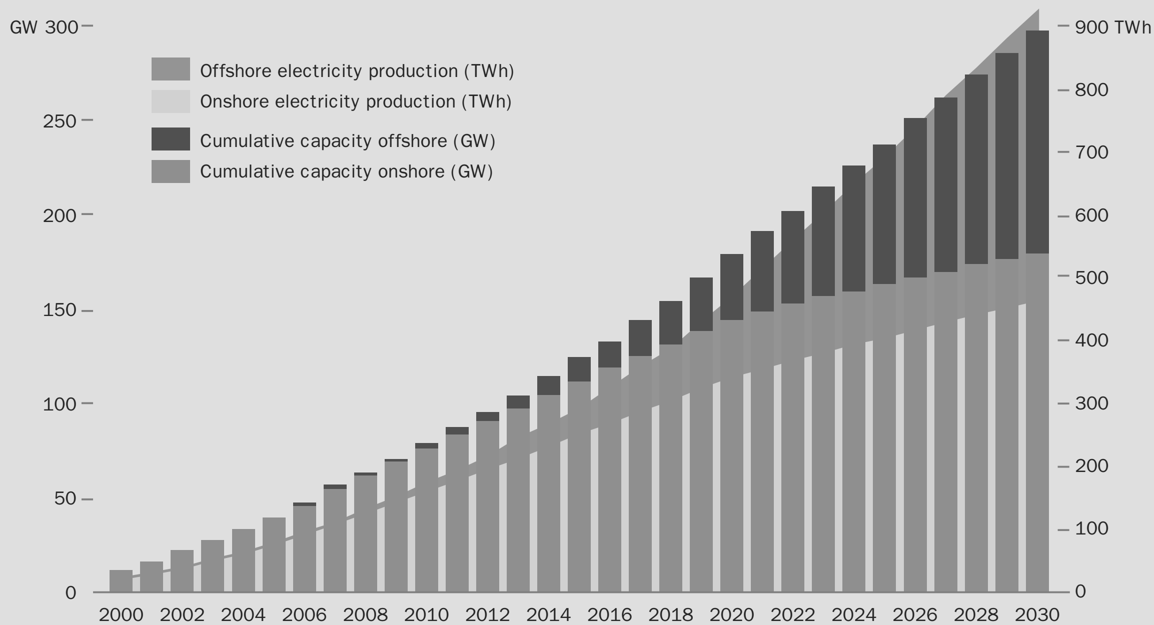
Total installations in the period from 2008 to 2030 will be 327 GW, made up of 207 GW onshore and 120 GW offshore. Of this, 83 GW will come from the replacement of decommissioned onshore capacity. Total investments between 2008 and 2030 will be €339 billion.

By 2030, wind energy will produce 935 TWh of electricity, half of it from offshore wind power, and cover between 21 per cent and 28 per cent of EU electricity demand, depending on future power consumption.

The onshore market will stabilise at approximately 10 GW per year throughout the decade 2020–2030 and 72 per cent of the onshore market will come from the replacement of older wind turbines. The offshore segment increases from an annual installation of 7.3 GW in 2021 to 9.5 GW in 2030.

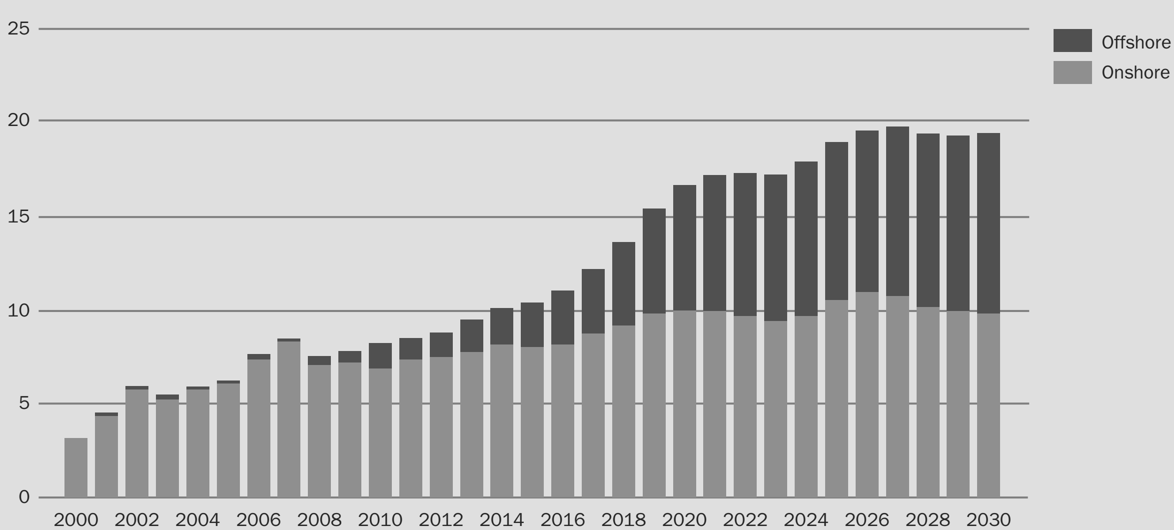
The wind power production in 2030 will avoid the emission of 575 Mt of CO_2, the equivalent of taking more than 280 million cars off the roads. In 2004 there were 216 million cars in the EU-25.

Figure VI.2.7: Electricity from wind to 2030



Source: EWEA (2008a)

Figure VI.2.8: Wind energy annual installations, 2000–2030 (in GW)



Source: EWEA (2008a)

VI.3 CONTRIBUTION OF WIND POWER TO ELECTRICITY GENERATION AND GENERATION CAPACITY IN THE EU-27

Contribution of Wind Power to Electricity Generation

European electricity generation is projected to increase at an average annual rate of 1.8 per cent between 2000 and 2010, 1.3 per cent in the decade 2010–2020, and 0.8 per cent in the decade up to 2030.

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. 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, 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.

Contribution of Wind Power to Generation Capacity

The IEA expects 5087 GW of electricity generating capacity to be installed worldwide in the period 2005–2030, requiring investments of US$5.2 trillion in power generation, $1.8 trillion in transmission grids and $4.2 trillion in distribution grids. The IEA expects 862 GW of this total to be built in the EU, requiring investments of $925 billion in new generation, $137 billion in transmission and $429 billion in distribution grids.

As already mentioned, wind power's contribution to new power capacity in the EU was exceeded only by gas in the last eight years. Thirty per cent of all installed capacity in the period 2000 to 2007 was wind power, 55 per cent was natural gas and 6 per cent was coal-based.

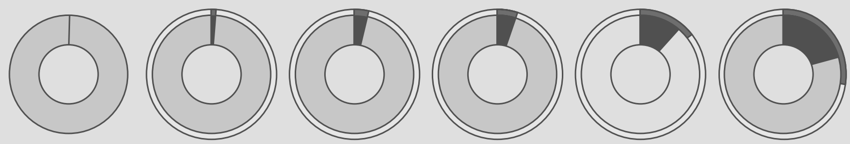
Spare electricity generating capacity is at a historic low and phase-out policies in the EU Member States require 27 GW of nuclear plants to be retired. Europe has to invest in new capacity to replace aging plants and meet future demand. Between 2005 and 2030, a total of 862 GW of new generating capacity needs to be built, according to the IEA – 414 GW to replace aging power plants and an additional 448 GW to meet the growing power demand. The capacity required exceeds the total capacity operating in Europe in 2005 (744 GW).

Table VI.3.1: 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

Figure VI.3.1: Wind power's share of EU electricity demand



	1995	2000	2007	2010	2020	2030
Wind energy share (reference)	0.2%	0.9%	3.7%	5.0%	11.6%	20.8%
Wind energy (RE & Eff. case)		0.9%	3.7%	5.2%	14.3%	28.2%
Wind power production (TWh)		23	119	176	477	935
Reference electricity demand (TWh)		2577	3243	3554	4107	4503
RE & Eff. case electricity demand (TWh)		2577	3243	3383	3345	3322

Source: EWEA (2008a)

The IEA is less optimistic about the development of wind energy than EWEA. Hence, it is necessary to adjust the IEA figures for total generating capacity and new capacity to take account of the fact that wind energy's capacity factor is lower than that of the average coal, gas or oil plant. Adjusting for the capacity factor adds 18 GW to total generating capacity in 2030 to make a total of 1176 GW, and 26 GW to the figure for new generating capacity between 2005 and 2030 to make a total of 889 GW over the period.

In 2005, 5.4 per cent of all electricity generating capacity in the EU was wind energy. That share is forecast to increase to 9.9 per cent in 2010, 18.1 per cent in 2020 and 25.5 per cent in 2030. Wind power's share of new generating capacity is forecast to be 34 per cent in the period 2005–2020 and 46 per cent in the decade up to 2030. Wind power's share of new capacity in Europe in the 25-year period 2005–2030 should be 39 per cent.

Table VI.3.2: Wind power's share of installed capacity

	2005	2010	2020	2030
Total installed capacity (GW)	744	811	997	1176
Total installed wind capacity (GW)	40	80	180	300
Wind power's share of installed capacity (%)	5.4	9.9	18.1	25.5

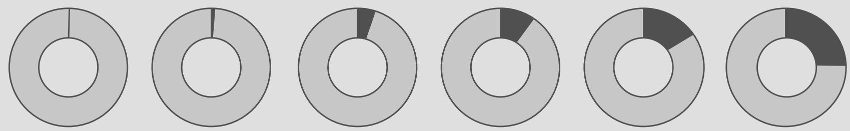
Scenarios of the European Commission and the IEA

BASELINE SCENARIOS

Both the European Commission and the International Energy Agency (IEA) publish baseline scenarios for the development of various electricity-generating technologies, including wind energy. In 1996, the European Commission estimated that 8000 MW would be installed by 2010 in the EU. The 8000 MW target was reached in 1999. The Commission's target for 2020 was set at 12,300 MW and reached, two decades ahead of schedule, in 2000.

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 8 GW to 71 GW (2010) and from 12 GW to 120 GW (2020) in the European Commission's latest baseline scenario from 2008. Surprisingly, the baseline scenario from 2008 gives significantly lower figures for wind energy than the baseline scenario from 2006. The 71 GW 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 the light of the current market achievements, growth

Figure VI.3.2: Wind power's share of installed capacity



	1995	2000	2005	2010	2020	2030
Wind power's share of installed capacity	0.46%	2.1%	5.4%	9.9%	18.1%	25.5%
Total installed capacity (GW)	538.8	580.7	744	811	997	1176
Total installed wind capacity (GW)	2.5	12.3	40	80	180	300

Source: EWEA (2008a)

Table VI.3.3: Wind power's share of new capacity

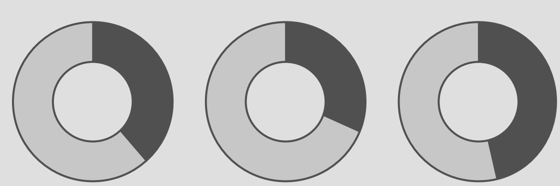
	2005–2010	2011–2020	2021–2030
New generating capacity (GW)	117	368	404
New wind generating capacity (GW)	46	117	187
Wind power's share of new capacity (%)	39	32	46

trends and independent market analyses, the European Commission's baseline scenario seems completely out of touch with the market reality, and clearly underestimates the sector's prospects.

Figure VI.3.4 shows the forecast for average annual installations (GW) up to 2030 according to the European Commission's 2008 baseline scenario and to EWEA's baseline, or 'reference', scenario compared with the 2007 market level.

Historically, EWEA's scenarios have been somewhat conservative, and its targets have been revised upwards numerous times. EWEA's 2010 target (based on its 'reference' scenario) was doubled from 40 GW (in 1997) to 80 GW (in 2006). The EWEA reference scenario for 2020 is 60 GW higher than the Commission's baseline scenario. For 2030, the Commission assumes 146 GW while EWEA assumes 300 GW.

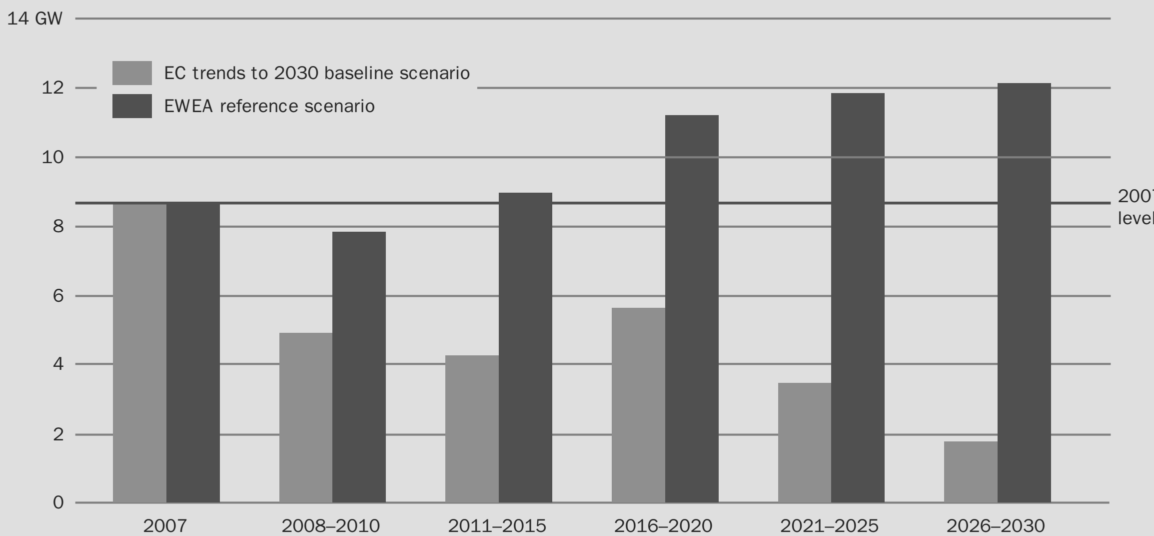
Figure VI.3.3: Wind power's share of new capacity



	2005–2010	2011–2020	2021–2030
Wind power's share of new capacity	39%	32%	46%
New generating capacity (GW)	117	368	404
New wind generating capacity (GW)	46	117	187

Source: EWEA (2008a)

Figure VI.3.4: European Commission baseline scenario compared with actual market and EWEA target



Source: EWEA statistics and *Pure Power* report; European Commission 2007 update of *European Energy and Transport – Trends to 2030*

Table VI.3.4 shows the European Commission's various scenarios for wind energy installations up to 2030, compared with the actual market up to 2008 and EWEA's 2007 scenario up to 2030.

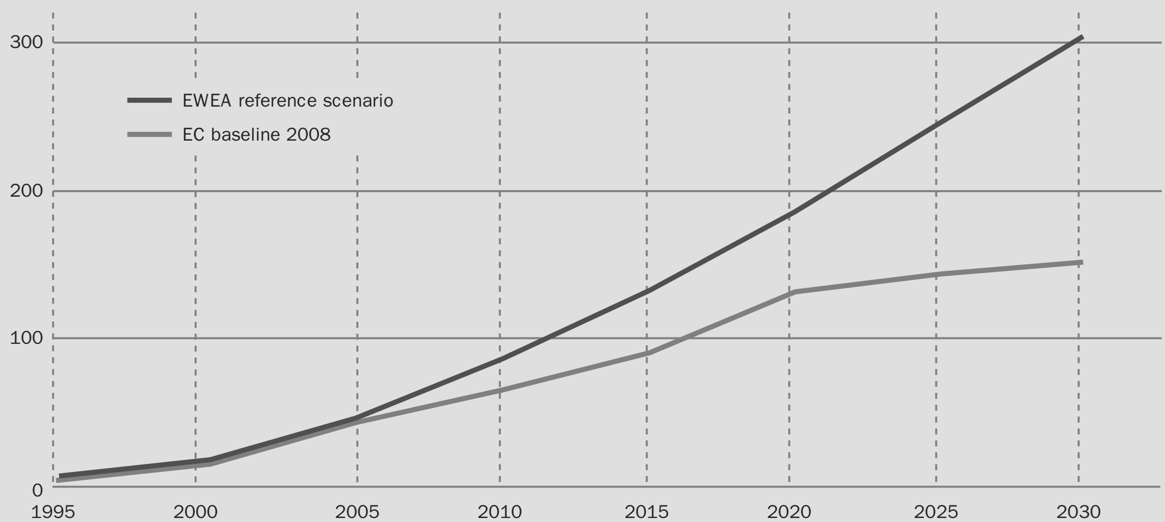
Figure VI.3.5 shows the European Commission's 2008 baseline scenario compared with the EWEA target up to 2030.

The IEA also produces baseline scenarios for the development of wind power. In 2002, the Agency estimated that 33 GW would be installed in Europe in 2010, 57 GW by 2020 and 71 GW by 2030. Two years later, in 2004, it doubled its forecast for wind energy to 66 GW in 2010, and more than doubled its 2020 and 2030 business-as-usual scenarios for wind in the EU to 131 GW in 2020 and 170 GW in 2030. In 2006, the IEA again increased its 2030 target for wind power in the EU to 217 GW (its alternative policy scenario assumes 227 GW). The IEA's reference scenario

Table VI.3.4: European Commission scenarios compared with actual market, EWEA 2008 reference scenario

	1995	2000	2005	2010	2015	2020	2025	2030
EC 1996		4.4	6.1	8.0	10.1	12.3		
EC 1999			15.3	22.6		47.2		
EC 2003				69.9		94.8		120.2
EC 2004	2.5	12.8		72.7		103.5		134.9
EC 2006		12.8	37.7	78.8	104.1	129.0	165.8	184.5
EC 2008 reference scenario			40.8	71.3	92.2	120.4	137.2	145.9
Actual market/EWEA 2007 target	2.497	12.887	40.5	80.0	124.5	180.0	239.3	300.0

Figure VI.3.5: European Commission's 2008 baseline scenario compared with the EWEA target up to 2030 (in GW)



Source: EWEA (2008a)

assumes 68 GW in 2010, 106 GW in 2015, 150 GW in 2020 and 217 GW in 2030. EWEA's reference scenario assumes 80 GW in 2010, 125 GW in 2015, 180 GW in 2020 and 300 GW in 2030.

The European Commission's baseline scenario claims to take 'into account the high energy import price environment', by assuming an oil price of US$55/barrel in 2005, $44.6/barrel in 2010 and $62.8/barrel in 2030. In its 2006 scenario, the IEA assumes an oil price of $47 in 2015, reaching $55 in 2030. In July 2008, the crude oil prices[4] reached an all-time high of $147 a barrel. At the time of writing, there are indications that the IEA will increase its oil price forecast for 2020 to the $100–$120 range.

Table VI.3.5 shows the IEA's various scenarios for wind energy installations in Europe up to 2030, compared with the actual market up to 2007, followed by EWEA's 2008 scenario up to 2030.

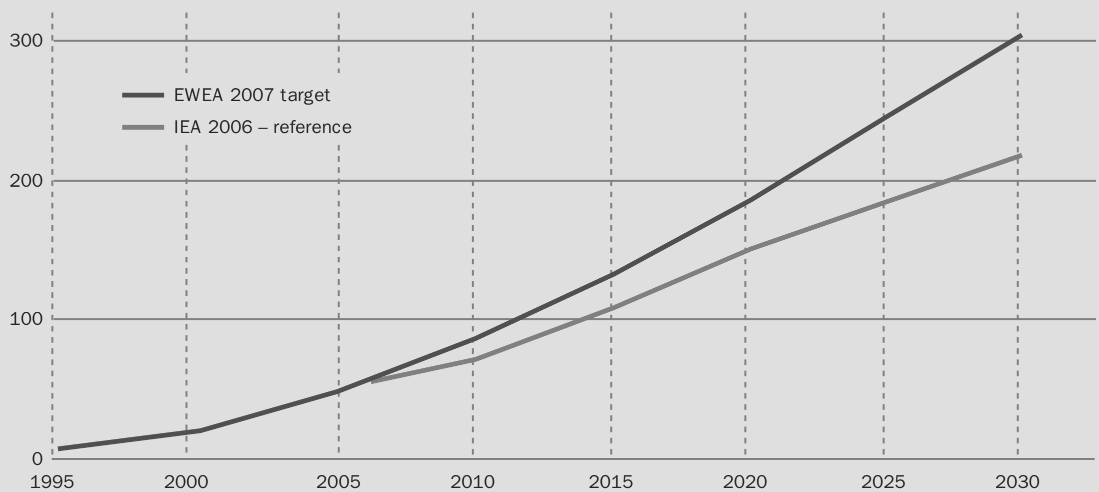
Figure VI.3.6 shows the IEA's 2006 reference scenario compared with the EWEA target up to 2030.

Table VI.3.5: IEA's scenarios up to 2030 compared with actual market/EWEA 2007 target

	1995	2000	2005	2010	2015	2020	2025	2030
IEA 2002				33.0		57.0		71.0
IEA 2004				66.0		131.0		170.0
IEA 2006 – reference				68.0	106.0	150.0		217.0
IEA 2006 – APS*				71.0	108.0	151.0		223.0
Actual market/EWEA 2007 target	2.5	12.9	40.5	80.0	124.5	180.0	239.3	300.0

*Alternative policy scenario

Figure VI.3.6: IEA's 2006 baseline scenario compared with the EWEA target up to 2030 (in GW)



Source: EWEA (2008a)

Table VI.3.6 shows EWEA's various scenarios for wind energy installations up to 2030, compared with the actual market up to 2007.

In its *World Energy Outlook 2006*, the IEA adopts a rather pessimistic view towards future wind energy installations around the globe, particularly as far as the US and the Chinese markets are concerned. Table VI.3.7 shows that a yearly averaging out of the installations required to reach the IEA 2015 cumulative target results in installation figures significantly below current market levels. At the time of writing, the IEA's *World Energy Outlook 2008* has not been published, but there are indications that the Agency's forecast for global wind energy development will be increased to better reflect market expectations.

ADVANCED SCENARIOS

In addition to the baseline/business-as-usual scenarios, the European Commission and the IEA have in recent years published more advanced scenarios with less static assumptions. The European Commission's

Table VI.3.6: EWEA's scenarios up to 2030 compared with the actual market/EWEA 2007 target

	1995	2000	2005	2010	2015	2020	2025	2030
EWEA 1997				40				
EWEA 2000				60		150		
EWEA 2003				75		180		
Actual market/ EWEA 2007 target	2.5	12.9	40.5	80	125	180	165	300

Table VI.3.7: GWEC and IEA 2015 cumulative targets, present market levels and projection of average yearly installations to reach the IEA 2015 target (reference scenario, GW)

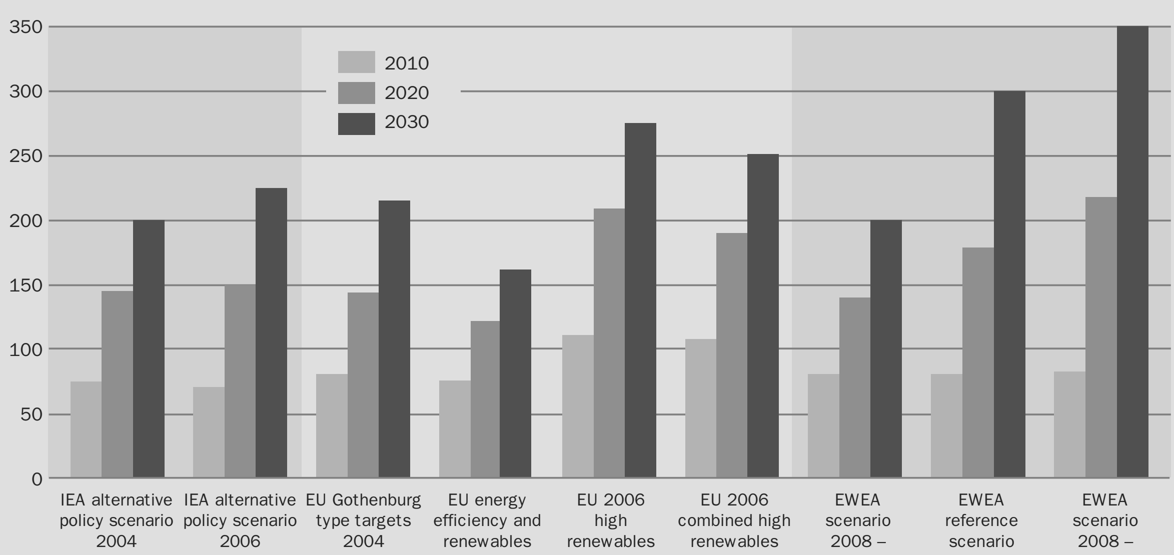
	2007 cumulative (GWEC)	2015 cumulative (IEA)	2007 annual (GWEC)	Average/year 2008–2015 (IEA)
World	93.9	168	19.9	9.2
OECD North America	18.7	30	5.6	1.4
European Union	56.5	106	8.5	6.2
China	5.9	7	2.6	0.1

Sources: GWEC (2008) and IEA *World Energy Outlook 2006*

new scenarios on energy efficiency and renewables from 2006 assume that 'agreed policies will be vigorously implemented in the Member States and that certain new targets on the overall share of renewables in 2020 will be broadly achieved'. However, the underlying estimates of fuel and carbon prices are no different from the baseline scenario.

Both the European Commission's and the IEA's advanced scenarios from 2004 are in line with the 80 GW target in 2010 from EWEA. However, the 2020 and 2030 targets from the IEA and the European Commission are significantly below EWEA's targets. The 2006 IEA alternative policy scenario for the EU (151 GW in 2020) is, somewhat surprisingly, only 1 GW higher than its reference scenario. Its 2030 alternative policy scenario is a mere 6 GW higher than its reference scenario (217 GW). The European Commission's advanced 2006 scenarios are more in line with the EWEA targets, and even exceed EWEA's targets for 2020.

Figure VI.3.7: Advanced scenarios for 2010, 2020 and 2030 (in GW)



Source: EWEA (2008a)

VI.4 COSTS AND BENEFITS OF WIND DEVELOPMENT IN THE EU-27

Generation Costs and Investments

One of the significant advantages of wind power is that 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 certainty. Neither the future prices of coal, oil or gas, nor the price of carbon, will affect the cost of wind power production significantly.

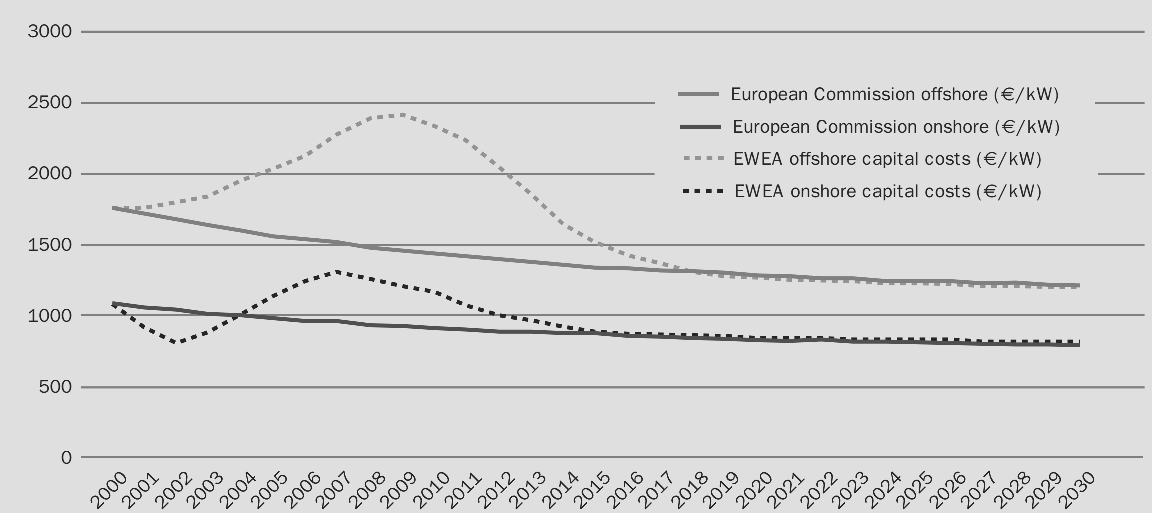
In order to calculate the wind power investments needed to reach EWEA's reference scenario, it is necessary to make assumptions regarding the future cost of installed wind power capacity. For some years, it has been assumed as a rule of thumb that installed wind power capacity costs approximately €1000/kW. That is probably still valid. However, since 2000 there have been quite large variations in the price (not necessarily the cost) of installing wind power capacity; these were described in Part III – The Economics of Wind Power.

In the period 2001 to 2004, the global market for wind power capacity grew less than expected, and created a surplus in wind turbine production capacity. Consequently, the price of wind power capacity went down dramatically – to €700–800/kW for some projects. In the three years to 2007, the global market for wind energy increased by 30–40 per cent annually, and demand for wind turbines surged, leading to increases in prices.

The European Commission, in its Renewable Energy Roadmap,[5] assumes that onshore wind energy cost €948/kW in 2007 (in $€_{2005}$). It assumes that costs will drop to €826/kW in 2020 and €788/kW in 2030. That long-term cost curve may still apply for a situation where there is a better balance between demand and supply for wind turbines than at the present time.

Figure VI.4.1 shows the European Commission's assumptions on the development of onshore and offshore wind power capacity costs up to 2030. In addition, there are two curves that reflect the effect of the current demand/supply situation on wind turbine prices in recent years. EWEA assumes onshore wind energy prices of €1300/kW in 2007 ($€_{2005}$ prices) and offshore prices of €2300/kW. The steep increase in

Figure VI.4.1: Cost/price of onshore and offshore wind (€/kW)



Source: EWEA (2008a)

offshore prices reflects the limited number of manufacturers in that market, the current absence of economies of scale due to low market deployment and bottlenecks in the supply chain.

Based on the EWEA reference scenario for installed capacity up to 2030 and the wind power capacity prices above, Figure VI.4.2 shows the expected annual wind power investments from 2000 to 2030. The market is expected to stabilise at around €10 billion per year up to 2015, with a gradually increasing share of investments going to offshore. By 2020, the annual market for wind power capacity will have grown to €17 billion annually, with approximately half of investments going to offshore. By 2030, annual wind energy investments in the EU-27 will reach almost €20 billion, with 60 per cent of investments offshore.

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. This can be broken down into €31 billion in 2008–2010, €120 billion in 2011–2020 and €188 billion in 2021–2030.

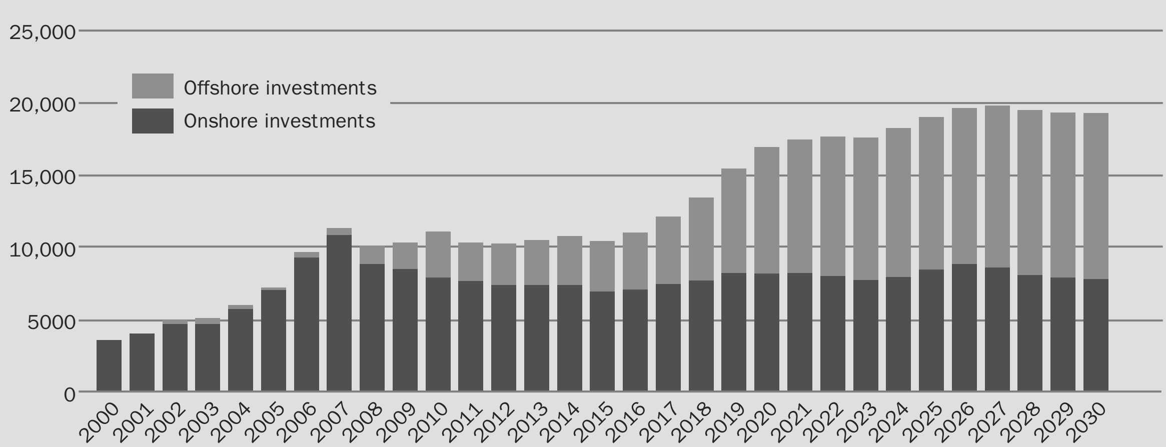
The IEA (2006) expects that €925 billion of investment in electricity generating capacity will be needed for the period 2005 to 2030 in the EU. According to the EWEA reference scenario, €367 billion – or 40 per cent – of that would be investment in wind power.

Avoided Fuel Costs

Fuel is not required to produce wind power. When wind energy is produced, it saves significant amounts of fuel costs in the form of coal, gas and oil that would otherwise have been needed for power production. In addition to these avoided costs, the production of wind energy reduces demand for imported fuel (and thereby the cost of fuel), while reducing the rate of depletion of Europe's remaining fossil fuel reserves.

Naturally, the avoided fuel costs of wind energy depend on the assumptions made about future fuel prices. Oil and gas prices are very closely linked, and coal also follows, to a lesser extent, the price of oil. Both the IEA and the European Commission have for many years made predictions on future coal, gas and oil prices, and most governments base their energy policies on the IEA's fuel price scenarios. Historically, the IEA and European Commission scenarios have been similar, and both institutions have been very consistent in underestimating the future fuel prices.

Figure VI.4.2: Wind energy investments, 2000–2030 (€m)



Source: EWEA (2008a)

Table VI.4.1: Oil price assumptions

Oil price assumptions (in $US\$_{2005}$)*	2000	2005	2007	2010	2015	2020	2025	2030
European Commission, 2007	31.3	57.1	68.9	54.5	57.9	61.1	62.3	62.8
International Energy Agency, 2007	31.5	57.1	68.9	57.2	55.5	57.0	58.5	60.1
EWEA, 2008	31.3	57.1	68.9	100.0	105.0	110.0	115.0	120.0

* Adjusted to 2005 prices/actual prices until 2007.

A barrel of oil cost US$100 at the start of 2008, and reached a record $147 in July. The IEA predicts that the oil price will fall to $57 in 2010. In 2004, the IEA predicted that oil would cost $22 a barrel in 2010, $26 in 2020 and $29 in 2030 (in year-2000 dollars).

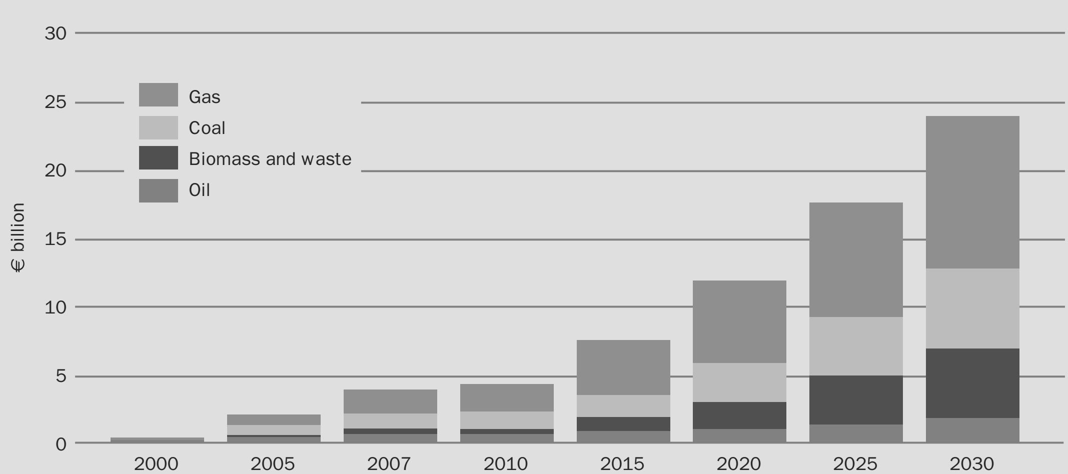
Table VI.4.1 shows the latest oil price estimates from the European Commission (2007) and the IEA (2007) and an alternative oil price scenario from EWEA. As the table shows, the European Commission believes that the price of oil in 2010 will be approximately 60 per cent lower than today (around $120 in September 2008), while the IEA estimates a drop in the price of oil to circa $57 three years from now. Both institutions believe that the price of oil in 2030 will be approximately $60 a barrel – 50 per cent lower than today.

Nobody can predict oil prices, but it should be a minimum requirement that the European Commission and the IEA include fuel price sensitivity analysis in their scenarios for the future development of the energy markets.

The fuel costs avoided due to wind energy production can be calculated on the basis of the European Commission's fuel price assumptions for coal, oil and gas up to 2030. As Figure VI.4.3 shows, wind energy avoided €3.9 billion of fuel costs in 2007: €1.7 billion worth of gas, €1.2 billion worth of coal, €0.7 billion worth of oil and €0.3 billion worth of biomass/waste. In EWEA's reference scenario, wind energy will avoid fuel costs of €4.4 billion in 2010, €12 billion in 2020 and €24 billion in 2030, based on the European Commission's fuel price assumptions. Similar results emerge from using the IEA fuel price assumptions.

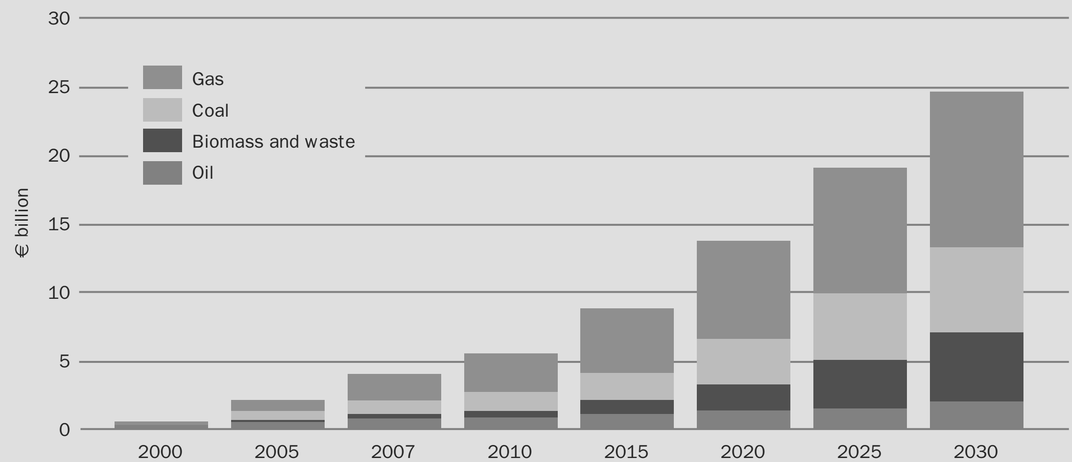
Assuming fuel prices equivalent to US$90 per barrel of oil, rather than the European Commission's

Figure VI.4.3: Avoided fuel cost from wind energy, 2000–2030 (European Commission fuel price assumption)



Source: EWEA (2008a)

Figure VI.4.4: Avoided fuel cost from wind energy, 2000–2030 (IEA fuel price assumption)



Source: EWEA (2008a)

assumptions, fuel costs avoided due to wind would be €5 billion in 2007, €8.3 billion in 2010, €20.5 billion in 2020 and €34.6 billion in 2030 (see Figure VI.4.5).

The calculations here are based on an €/US$ exchange rate of 0.6838 (February 2008). Fluctuations in exchange rates can have a profound effect on the avoided fuel cost. Had the €/$ exchange rate been 1, wind energy's avoided fuel cost would have been €50.5 billion in 2030 instead of €34.6 billion. However, it could reasonably be argued that the price of oil would be lower if the US dollar were stronger.

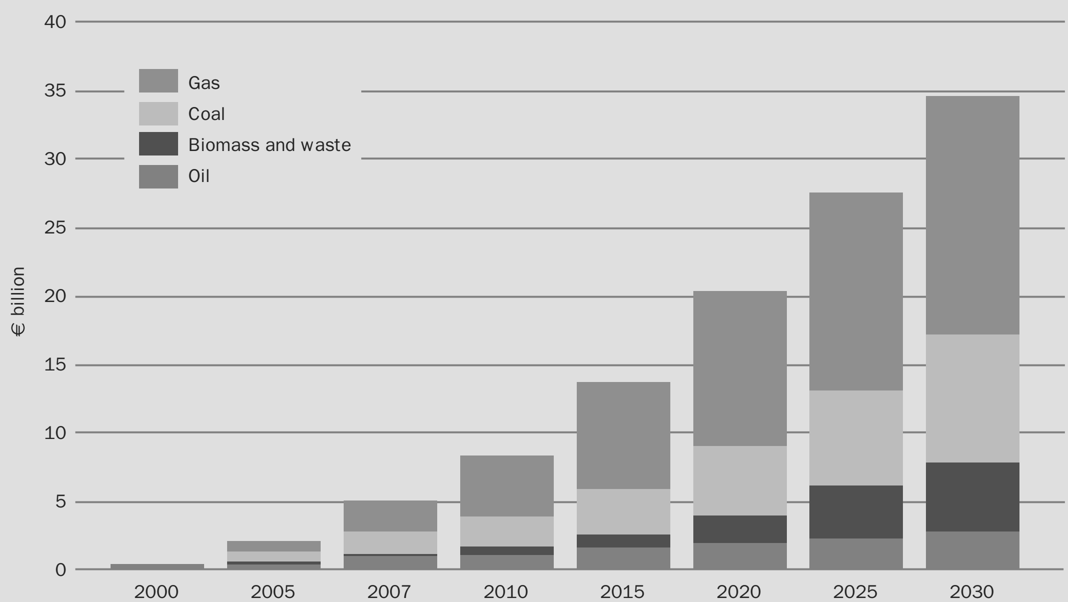
In EWEA's fuel price scenario – the oil price increases gradually from $90 to $120 in 2030, and the relationship between oil, gas and coal remains unchanged from the Commission's scenario – wind energy would avoid fuel costs worth €9.2 billion in 2010, €24.6 billion in 2020 and €44.4 billion in 2030 (see Figure VI.4.6).

Investments and Total Avoided Lifetime Cost

So far, Part VI has looked at wind energy's contribution to electricity, CO_2 reductions, avoided fuel cost and so on from a perspective of total installed capacity by the end of each individual year. In this chapter, a lifetime approach is used in order to determine how much CO_2 and fuel cost are avoided from wind power investments made in a given year over the entire lifetime of the capacity. For example, the 300 GW of wind power capacity installed in the EU in 2030 will avoid the emission of 576 Mt of CO_2 in the same year. What has not been taken into account so far in this report is that the wind energy capacity installed – for example, the 19.5 GW that will be installed in 2030 – will continue to produce electricity and avoid CO_2 and fuel costs beyond 2030 – some CO_2 and fuel costs will be avoided right up to 2055.

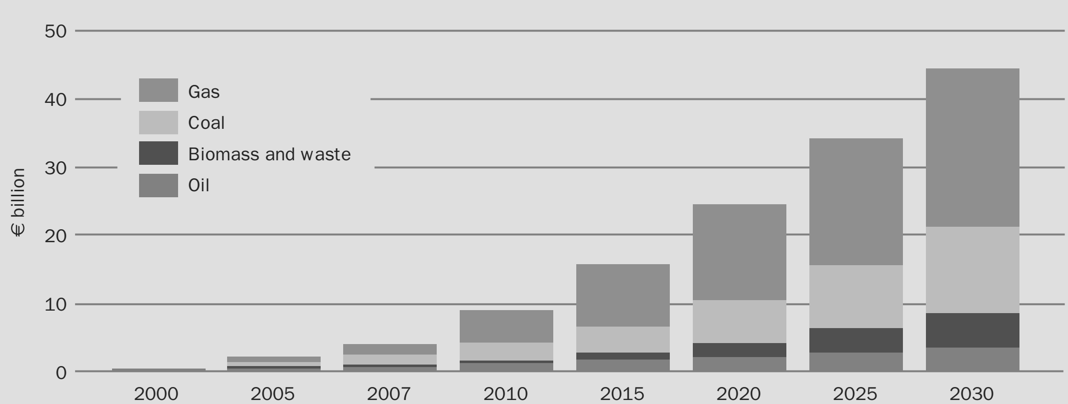
Figure VI.4.7 (the scenario with oil at $90 and CO_2 at €25) shows the total CO_2 costs and fuel costs avoided during the lifetime of the wind energy capacity installed for each year from 2008 to 2030, assuming a technical lifetime for onshore wind turbines of 20 years and for offshore wind turbines of 25 years. Furthermore, it is assumed that wind energy avoids 690 g of CO_2 per kWh produced, that the average price of a CO_2 allowance is €25/t and that €42 million worth of fuel is avoided for each TWh of wind power produced, equivalent to an oil price throughout the period of $90 per barrel.

Figure VI.4.5: Avoided fuel cost from wind energy, 2000–2030 (fuel price equivalent to January 2008 – US$90/barrel – until 2030)



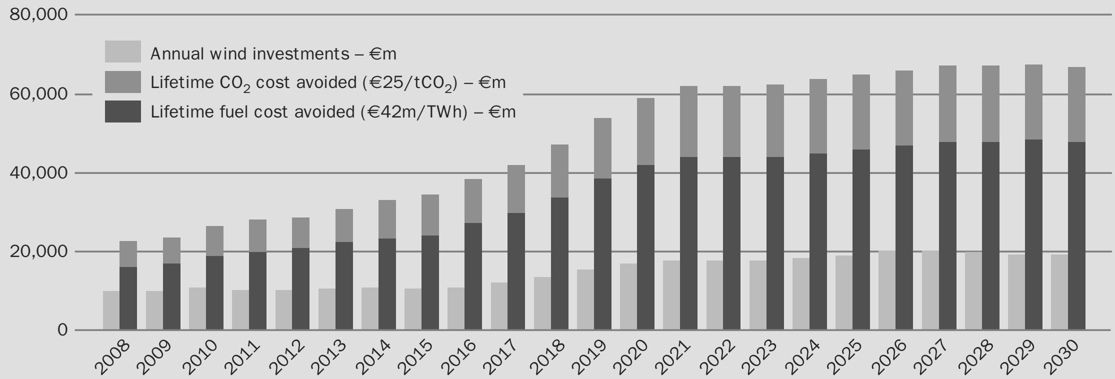
Source: EWEA (2008a)

Figure VI.4.6: Avoided fuel cost from wind energy, 2000–2030 (fuel price increase to US$100 in 2010, $110 in 2020 and $120 in 2030)



Source: EWEA (2008a)

Figure VI.4.7: Wind investments compared with lifetime avoided fuel and CO_2 costs (oil at US$90/barrel; CO_2 at €25/t)



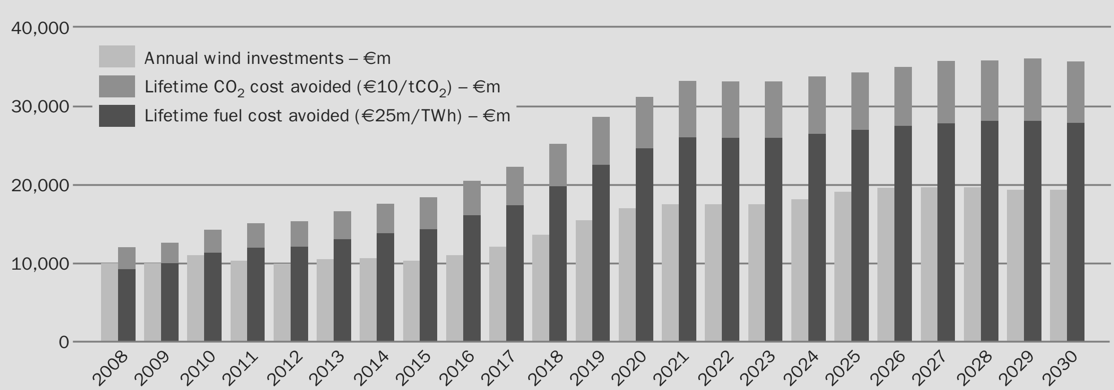
Source: EWEA (2008a)

For example, the 8554 MW of wind power capacity that was installed in the EU in 2007 had an investment value of €11.3 billion and will avoid CO_2 emissions worth €6.6 billion throughout its lifetime and fuel costs of €16 billion throughout its lifetime, assuming an average CO_2 price of €25/t and average fuel prices (gas, coal and oil) based on $90/barrel of oil.

Similarly, the €152 billion of investments in wind power between 2008 and 2020 will avoid €135 billion worth of CO_2 and €328 billion in fuel cost under the same assumptions. For the period up to 2030, wind power investments of €339 billion will avoid €322 billion in CO_2 cost and €783 billion worth of fuel.

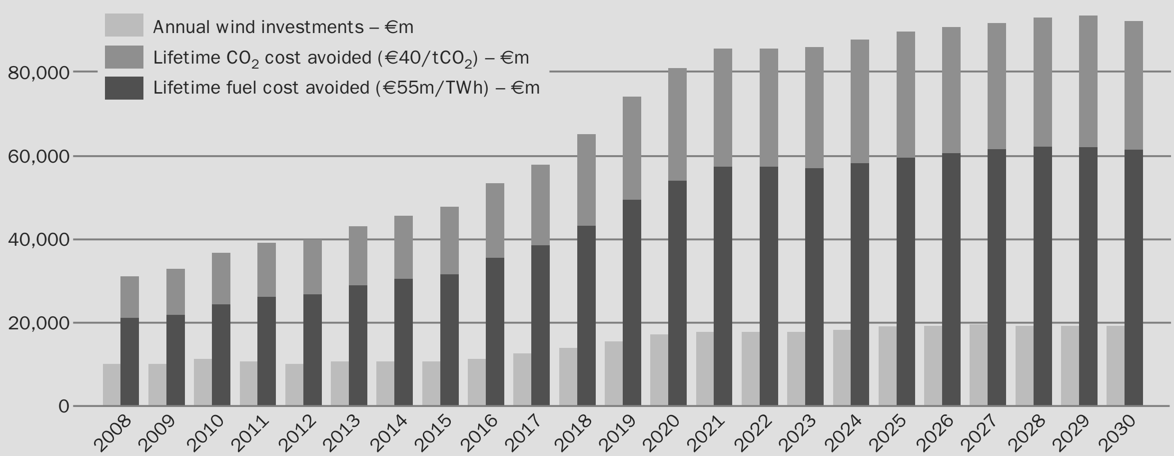
It is important to note that these calculations only compare the capital cost of wind energy to avoided CO_2 and fuel cost. The operation and maintenance cost (low because the fuel is free) has not been taken into account. In addition, it would be reasonable to assume that some components of the wind turbine would need replacing during their technical lifetime.

Figure VI.4.8: Wind investments compared with lifetime avoided fuel and CO_2 costs (oil at US$50/barrel; CO_2 at €10/t)



Source: EWEA (2008a)

Figure VI.4.9: Wind investments compared with lifetime avoided fuel and CO_2 costs (oil at US$120/barrel; CO_2 at €40/t)



Source: EWEA (2008a)

Table VI.4.2: The different savings made depending on the price of oil (per barrel) and CO_2 (per tonne)

Totals (oil US$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 (oil US$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	8,406	45,556	74,753	53,962	128,714
Avoided fuel cost	30,456	165,057	270,843	195,513	466,356
Totals (oil US$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

This has not been taken into account either. The purpose is simply to compare the investment value in an individual year with the avoided fuel and CO_2 cost over the lifetime of the wind turbines.

As can be seen from Table VI.4.2, changing the CO_2 and fuel price assumptions has a dramatic impact on the result. With low CO_2 prices (€10/tonne) and fuel prices (equivalent to $50/barrel of oil) throughout the period, wind power investments over the next 23 years avoid €466 billion instead of €783 billion. With high prices for CO_2 (€40/tonne) 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.

VI.5 GLOBAL SCENARIOS

Global Market Forecast for 2008–2012

The Global Wind Energy Council (GWEC) predicts that the global wind market will grow by over 155 per cent from 2007 to reach 240.3 GW of total installed capacity by 2012 (GWEC, 2008). This would represent an addition of 146.2 GW in five years, attracting investment of over €180 billion (US$277 billion, both in 2007 values). The electricity produced by wind energy will reach over 500 TWh in 2012 (up from 200 TWh in 2007), accounting for around 3 per cent of global electricity production (up from just over 1 per cent in 2007).

The main areas of growth during this period will be North America and Asia, more specifically the US and China. The emergence of significant manufacturing capacity in China by foreign and domestic companies will also have an important impact on the growth of the global markets. While tight production capacity is going to remain the main factor limiting further market growth, Chinese production may help take some of the strain out of the current supply situation.

The average growth rates during this five-year period in terms of total installed capacity are expected to be 20.7 per cent, compared with 23.4 per cent during 2003–2007. In 2012, Europe will continue to house the largest wind energy capacity, with a total of 102 GW, followed by Asia with 66 GW and North America with 61.3 GW.

The yearly additions in installed capacity are predicted to grow from 19.9 GW in 2007 to 36.1 GW in 2012, with an average growth rate of 12.7 per cent. Considering that annual markets have been increasing by an average of 24.7 per cent over the last five years, growth could be much stronger in the future were it not for continuing supply chain difficulties which will considerably limit the growth of annual markets for the next two years. This problem should be overcome by 2010, and along with the development of the offshore market, growth rates are expected to recover in the next decade.

GWEC predicts that Asia will install 12.5 GW of new wind generating capacity in 2012, up from 5.2 GW in 2007. This growth will be mainly led by China, which since 2004 has doubled its total capacity every year, thereby consistently exceeding even the most optimistic predictions. By 2010, China could be the biggest national market globally. This development is underpinned by a rapidly growing number of domestic and foreign manufacturers operating in the Chinese market.

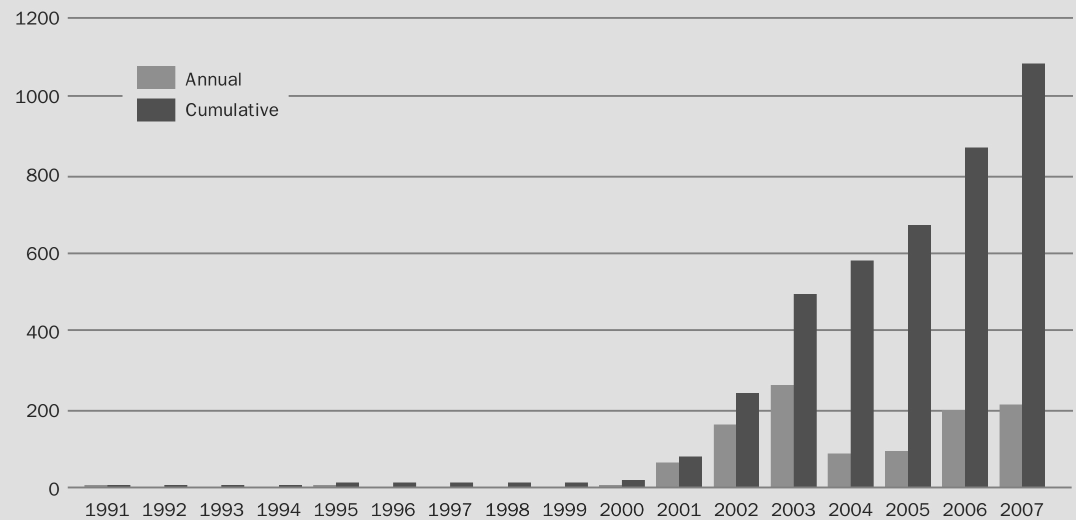
While China will emerge as the continental leader in Asia, sustained growth is also foreseen in India, while other markets such as Japan, South Korea and Taiwan will also contribute to the development of wind energy on the continent.

By 2012, the European market should stand at 10.3 GW – the same size as the North American market (10.5 GW). Overall, this means that over 29 per cent of global new installations will take place in Europe in 2012. In terms of total installed capacity, Europe will continue to be the biggest regional market, with 42.4 per cent of all wind power capacity installed in the world by the end of 2012.

The large-scale development of offshore wind energy will only start to have a significant impact on European market growth towards the end of the time period under consideration. However, it is expected that offshore development will lend momentum to growth in Europe during the next decade.

In Europe, Germany and Spain will remain the leading markets, but their relative weight will decrease as other national markets emerge on the scene. While the spectacular growth of the Spanish market in 2007, with over 3.5 GW of new installations, will not be sustained, a stable pace of 2–2.5 GW per year on average can be expected, enabling Spain to reach the government's 2010 target of 20 GW. The size of the German annual market will decrease, but it will remain the second strongest European market for the 2008–2012 period and the biggest in terms of total installed capacity. By 2010, offshore developments will give new impetus to the German market, resulting in stronger

Figure VI.5.1: Offshore wind in the EU

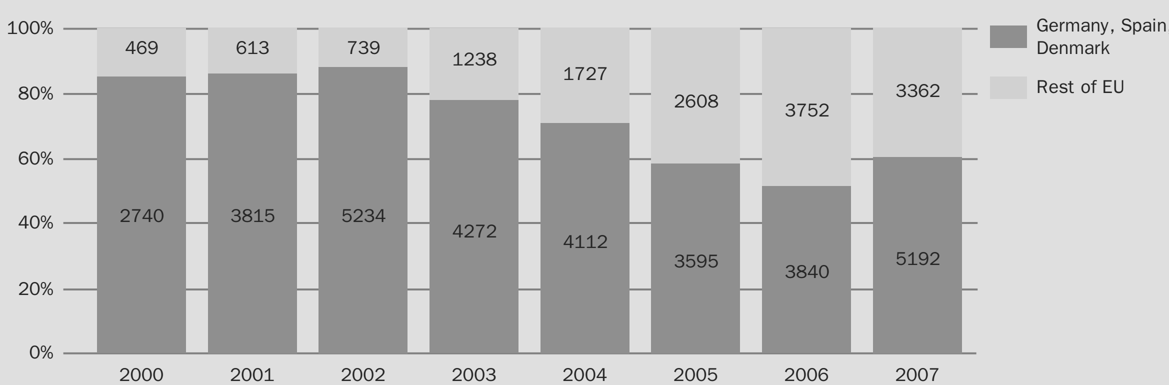


Source: EWEA (2008a)

growth. Other important markets in Europe will be France and the UK, each increasing by an average of 1 GW per year.

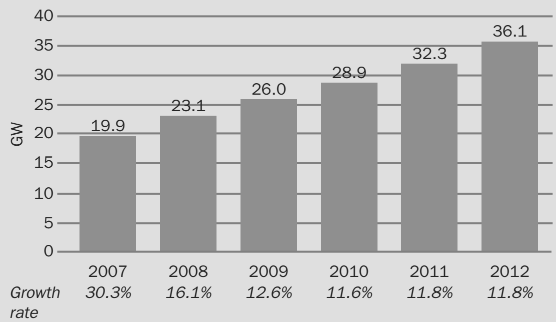
The North American market will see strong growth, led by the US, with the Canadian market maintaining its development. In total, North America will see an addition of 42.6 GW in the next five years, reaching 61.3 GW of total capacity in 2012. This represents an average of 8.5 GW of new capacity added every year (the bulk of which is in the US).

Figure VI.5.2: Germany, Spain and Denmark's share of EU market, 2000–2007



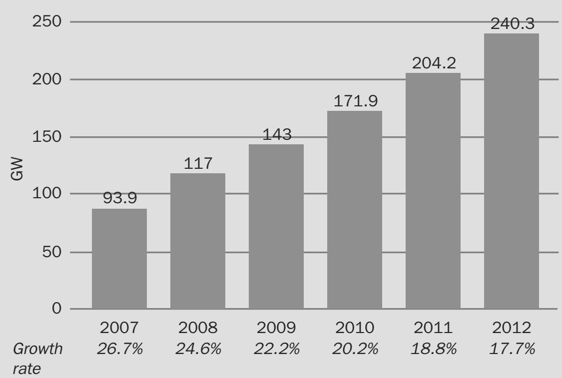
Source: EWEA (2008a)

Figure VI.5.3: Annual global installed capacity, 2007–2012



Source: GWEC

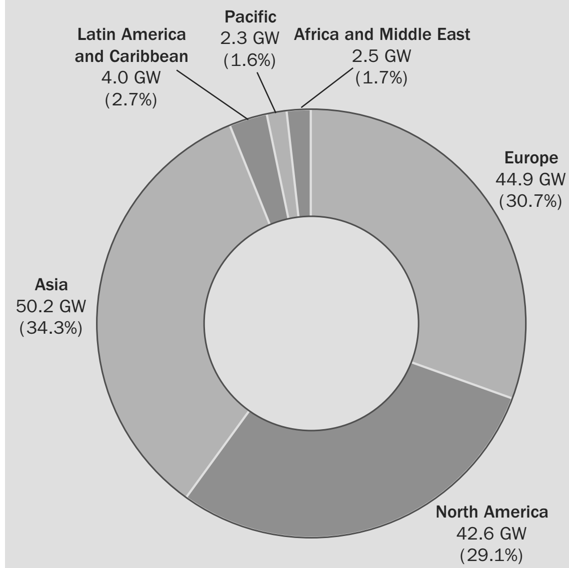
Figure VI.5.4: Cumulative global installed capacity, 2007–2012



Source: GWEC

These figures assume that the US Production Tax Credit (PTC) will be renewed in time for the current strong growth to continue. If it is not, the 2009 market could suffer. However, the high-level engagement of an increasing number of US states, 27 of which have already introduced Renewable Portfolio Standards, will also assure sustained growth. A change in the US administration may further underpin this development.

Figure VI.5.5: New global installed capacity, 2008–2012

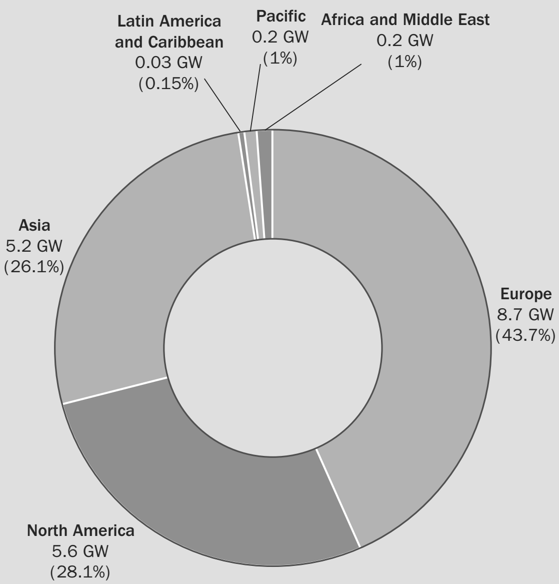


Source: GWEC

Figure VI.5.6: Cumulative global installed capacity, end 2007

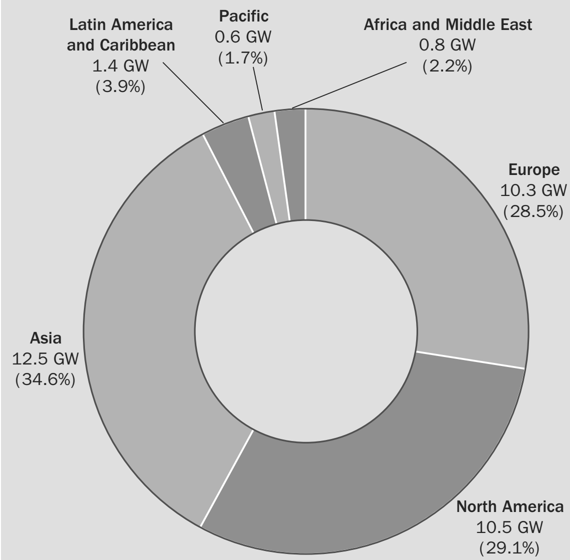
Source: GWEC

Figure VI.5.7: Annual capacity in 2007



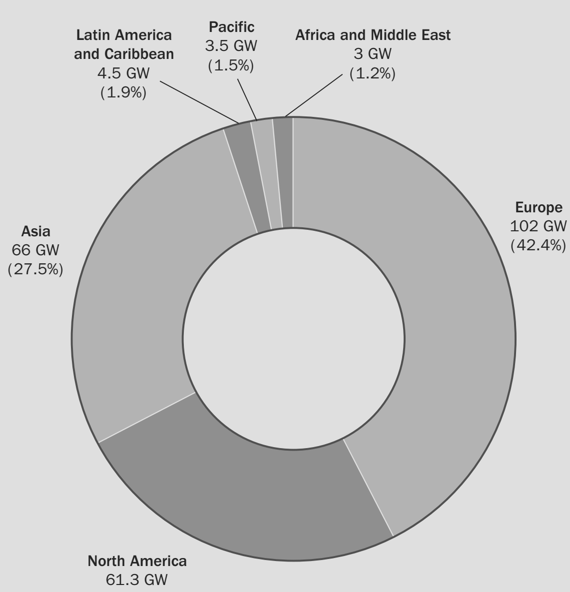
Source: GWEC

Figure VI.5.9: Annual capacity in 2012



Source: GWEC

Figure VI.5.8: Cumulative capacity, end 2012



Source: GWEC

Latin America is expected to contribute more substantially to the global total in the future, mainly driven by Brazil, Mexico and Chile. By 2012, the total installed capacity in Latin America and the Caribbean will increase eightfold to reach 4.5 GW, and an annual market of 1.4 GW. However, despite its tremendous potential, Latin America is likely to remain a small market until the end of the period under consideration, progressing towards more significant development in the next decade.

The Pacific region will see around 2.3 GW of new installations in 2008–2012, bringing the total up to 3.5 GW. While in Australia, wind energy development slowed down considerably in 2006 and 2007, the outlook for the future is more optimistic, mainly thanks to the change in federal government at the end of 2007, the ratification of the Kyoto Protocol and the pledge to implement a new target for 20 per cent of electricity from renewables by 2020. New Zealand, however, got new impetus with 151 MW of new installations in

2007, and many more projects are at various stages of development.

Africa and the Middle East will remain the region with the smallest wind energy development, with a total installed capacity of 3 GW by 2012, up from 500 MW in 2012. However, it is expected that market growth will pick up in the coming five years, with annual additions reaching around 800 MW by 2012. This development will be driven by Egypt and Morocco, with some development also predicted in other North African and Middle Eastern countries.

VI.6 THE 'GLOBAL WIND ENERGY OUTLOOK' SCENARIOS

The Global Wind Energy Outlook scenarios as presented by GWEC and Greenpeace (GWEC/Greenpeace, 2008) examine the future potential of wind power up to 2030, starting from a range of assumptions which will influence the development of the wind industry.

This exercise has been carried out jointly by GWEC, Greenpeace International and the German Aerospace Centre (DLR). Projections on the future of wind energy development have been extrapolated from a larger study of global sustainable energy pathways up to 2030, conducted by DLR for Greenpeace and the European Renewable Energy Council (EREC).

Scenario Methodology

REFERENCE SCENARIO

There are three different Global Wind Energy Outlook scenarios looking at the future growth of wind energy around the world. The most conservative 'reference' scenario is based on the projections in the *World Energy Outlook 2007* report from the IEA. This only takes existing energy policies into account, though including assumptions such as continuing electricity and gas market reform, the liberalisation of cross-border energy trade, and recent policies aimed at combating pollution. Based on the IEA's figures, the scenario then projects the growth of wind power up to 2030.

MODERATE SCENARIO

The 'moderate' scenario takes into account all existing or planned policy measures from around the world that support renewable energy. It also assumes that the targets set by many countries for either renewables or wind energy are successfully implemented. Moreover, it assumes renewed investor confidence in the sector established by a successful outcome from the current round of climate change negotiations, which are set to culminate at the UNFCCC COP 15 in Copenhagen in December 2009.

ADVANCED SCENARIO

The most ambitious scenario, the 'advanced' version examines the extent to which this industry could grow in a best-case 'wind energy vision'. The assumption here is that all policy options in favour of renewable energy, following the industry's recommendations, have been selected, and that the political will is there to carry them out.

Up to 2012, the figures for installed capacity are closer to being forecasts than scenarios. This is because the data available from the wind energy industry shows the expected growth of worldwide markets over the next five years based on orders for wind turbines that have already been received. After 2012, the pattern of development is clearly much more difficult to predict. Nonetheless, the scenario still shows what could be achieved if the wind energy market is given the encouragement it deserves.

Energy Efficiency Projections

These three scenarios for the global wind energy market are then set against two projections for the future growth of electricity demand. Most importantly, these projections do not just assume that growing demand by consumers will inevitably need to be matched by supply options. On the basis that demand will have to be reduced if the threat of climate change is to be seriously tackled, they take into account an increasing element of energy efficiency.

The more conservative of the two global electricity demand projections is again based on data from the IEA's *World Energy Outlook 2007*, extrapolated forwards to 2050. This is the 'reference' projection. It does not take into account any possible or likely future policy initiatives and assumes, for instance, that there will be no change in national policies on nuclear power. The IEA's assumption is that 'in the absence of new government policies, the world's energy needs will rise inexorably'. Global demand would therefore almost double from the baseline 12,904 TWh in 2002 to reach 29,254 TWh by 2030 and continue to grow to 42,938 TWh by 2050.

The IEA's expectations on rising energy demand are then set against the outcome of a study on the potential effect of energy-efficiency savings developed by DLR and the Ecofys consultancy. The study describes an ambitious development path for the exploitation of energy-efficiency measures. It focuses on current best practice and available technologies in the future, and assumes that continuous innovation takes place. The most important sources of energy saving are in efficient passenger and freight transport and in better insulated and designed buildings: together these account for 46 per cent of worldwide energy savings.

Under the 'high energy efficiency' projection, input from the DLR/Ecofys models shows the effect of energy-efficiency savings on the global electricity demand profile. Although this assumes that a wide range of technologies and initiatives have been introduced, their extent is limited by the potential barriers of cost and other likely roadblocks. This still results in global demand increasing by much less than under the reference projection, to reach 21,095 TWh in 2030. By the end of the scenario period in 2050, demand is 35 per cent lower than under the reference scenario.

Main Assumptions and Parameters

GROWTH RATES

Market growth rates in this scenario are based on a mixture of historical figures and information obtained from analysts of the wind turbine market. Annual growth rates of more than 20 per cent per annum, as envisaged in the advanced version of the scenario, are high for an industry which manufactures heavy equipment. The wind industry has experienced much higher growth rates in recent years, however. In the five years up to 2007 the average annual increase in global cumulative installed capacity was 25 per cent.

It should also be borne in mind that, whilst growth rates eventually decline to single figures across the range of scenarios, the level of wind power capacity envisaged in 40 years' time means that even small percentage growth rates will by then translate into large figures in terms of annually installed megawatts.

TURBINE CAPACITY

Individual wind turbines have been steadily growing in terms of their nameplate capacity – the maximum electricity output they can achieve when operating at full power. The average nameplate capacity of wind turbines installed globally in 2007 was 1.49 MW. The largest turbines on the market are now 6 MW in capacity.

GWEC's scenarios make the conservative assumption that the average size will gradually increase from today's figure to 2 MW in 2013 and then level out. It is possible, however, that this figure will turn out to be greater in practice, requiring fewer turbines to achieve the same installed capacity. It is also assumed that each turbine will have an operational lifetime of 20–25 years, after which it will need to be replaced. This 'repowering' or replacement of older turbines has been taken into account in the scenarios.

CAPACITY FACTORS

'Capacity factor' refers to the percentage of its nameplate capacity that a turbine installed in a particular location will deliver over the course of a year. This is primarily an assessment of the wind resource at a given site, but capacity factors are also affected by the efficiency of the turbine and its suitability for the particular location. As an example, a 1 MW turbine operating at a 25 per cent capacity factor will deliver 2190 MWh of electricity in a year.

From an estimated average capacity factor today of 25 per cent, the scenario assumes that improvements in both wind turbine technology and the siting of wind farms will result in a steady increase. Capacity factors are also much higher out to sea, where winds are stronger and more constant. The growing size of the offshore wind market, especially in Europe, will therefore contribute to an increase in the average.

The scenario foresees the average global capacity factor increasing to 28 per cent by 2012.

CAPITAL COSTS AND PROGRESS RATIOS

The capital cost of producing wind turbines has fallen steadily over the past 20 years, as manufacturing techniques have been optimised, turbine design has been largely concentrated on the three-bladed upwind model with variable speed and pitch regulation, and mass production and automation have resulted in economies of scale.

The general conclusion from industrial learning curve theory is that costs decrease by some 20 per cent each time the number of units produced doubles. A 20 per cent decline is equivalent to a progress ratio of 0.80.

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 here is at 0.90 up until 2009. After that it goes down to 0.80 before steadily rising again from 2016 onwards.

The reason for this graduated assumption, particularly in the early years, is that the manufacturing industry has not so far gained the full benefits of series production, especially due to the rapid upscaling of products. Neither has the full potential of future design optimisations been realised.

Contrary to this theory, the past few years, particularly since 2006, have seen a marked increase in the price of new wind turbines. This has been triggered by a mixture of rising raw material prices and shortages in the supply chain for turbine components. Examples of raw materials whose price has increased substantially are steel (used in towers, gearboxes and rotors), copper (used in generators) and concrete (used in foundations and towers). Global steel prices have almost doubled in the current year up to August 2008, while copper prices have quadrupled in the last five years. In addition, rising energy prices have also driven up the cost of manufacturing and transporting wind turbines. Supply chain pressures have included in particular a shortage of gearboxes and of the range of bearings used throughout the manufacturing of turbines. These shortages are being addressed by the component manufacturers, who are building new production capacity and opening up new manufacturing bases, for example in China. Some observers predict that component supply may catch up with demand by 2010.

Even so, the cost of wind turbine generators has still fallen significantly overall, and the industry is recognised as having entered the 'commercialisation phase', as understood in learning curve theories.

Capital costs per kilowatt of installed capacity are taken as an average of €1300 in 2007, rising to €1450 in 2009. They are then assumed to fall steadily from 2010 onwards to about €1050. From 2020 the scenario assumes a levelling out of costs. All figures are given at 2007 prices.

Scenario Results

An analysis of the Global Wind Energy Outlook scenarios shows that a range of outcomes is possible for the global wind energy market. The outcomes differ according to the choice of demand-side options and the assumptions for growth rates on the wind power supply side.

REFERENCE SCENARIO

The reference scenario, which is derived from the IEA's *World Energy Outlook 2007*, starts off with an assumed growth rate of 27 per cent for 2008, decreasing to 10 per cent by 2010, then falling to 4 per cent by 2030.

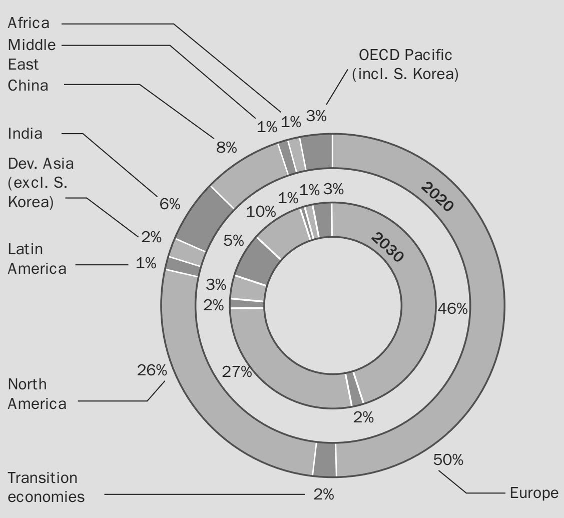
As a result, the scenario foresees cumulative global capacity reaching 139 GW, producing 304 TWh per year and covering 1.7 per cent of the world's electricity demand by the end of this decade. By 2020, global capacity would stand at 352 GW, growing to almost 500 GW by 2030, with an annual capacity increase of around 30 GW.

The relative penetration of wind energy into the global electricity supply system varies according to which demand projection is considered. Around 864 TWh produced in 2020 would account for between 3.6 per cent and 4.1 per cent of the world's electricity production, depending on the extent of the energy-efficiency measures introduced. By 2030, production of 1218 TWh would only meet 4.2–5.1 per cent of global demand.

MODERATE SCENARIO

In the moderate wind energy scenario, growth rates are expected to be substantially higher than in the reference version. The assumed cumulative annual growth rate starts at 27 per cent for 2008, decreases

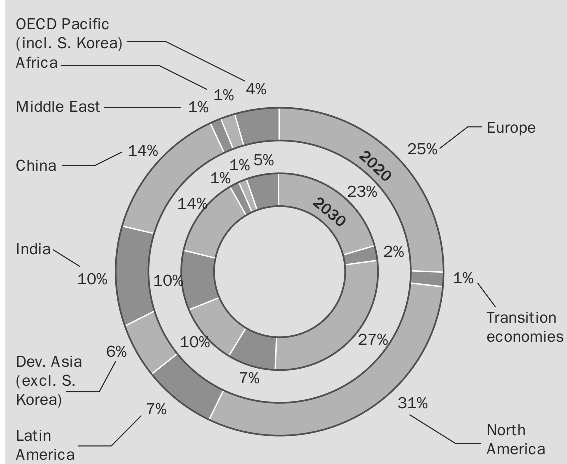
Figure VI.6.1: Regional distribution – Reference scenario 2020 and 2030



2020		2030	
Europe	176 GW	Europe	227 GW
Transition economies	7 GW	Transition economies	11 GW
North America	92 GW	North America	132 GW
Latin America	5 GW	Latin America	8 GW
Dev. Asia (excl. S. Korea)	7 GW	Dev. Asia (excl. S. Korea)	16 GW
India	20 GW	India	27 GW
China	27 GW	China	49 GW
Middle East	2 GW	Middle East	4 GW
Africa	4 WG	Africa	7 GW
OECD Pacific (incl. S. Korea)	12 GW	OECD Pacific (incl. S. Korea)	16 GW

Source: GWEC

Figure VI.6.2: Regional distribution – Moderate scenario 2020 and 2030



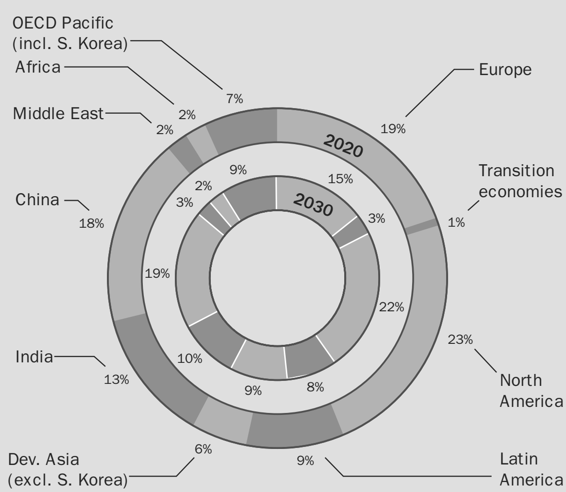
2020		2030	
Europe	182 GW	Europe	306 GW
Transition economies	9 GW	Transition economies	34 GW
North America	214 GW	North America	366 GW
Latin America	50 GW	Latin America	103 GW
Dev. Asia (excl. S. Korea)	40 GW	Dev. Asia (excl. S. Korea)	140 GW
India	69 GW	India	142 GW
China	101 GW	China	201 GW
Middle East	8 GW	Middle East	20 GW
Africa	10 GW	Africa	21 GW
OECD Pacific (incl. S. Korea)	30 GW	OECD Pacific (incl. S. Korea)	70 GW

Source: GWEC

to 19 per cent by 2010, and continues to fall gradually to 11 per cent by 2020 and 3 per cent by 2030.

The result is that by the end of this decade, the global wind power capacity is expected to reach 172 GW, with annual additions of 28.9 GW. By 2020, the annual market grows to 81.5 GW, and the cumulative global wind power capacity reaches a level of over 700 GW. By 2030, a total of over 1420 MW would be installed, with annual installations in the region of 84 GW.

Figure VI.6.3: Regional distribution – Advanced scenario 2020 and 2030



2020		2030	
Europe	213 GW	Europe	353 GW
Transition economies	10 GW	Transition economies	75 GW
North America	243 GW	North America	520 GW
Latin America	100 GW	Latin America	201 GW
Dev. Asia (excl. S. Korea)	61 GW	Dev. Asia (excl. S. Korea)	211 GW
India	138 GW	India	235 GW
China	201 GW	China	451 GW
Middle East	25 GW	Middle East	63 GW
Africa	17 GW	Africa	52 GW
OECD Pacific (incl. S. Korea)	75 GW	OECD Pacific (incl. S. Korea)	215 GW

Source: GWEC

In terms of generated electricity, this would translate into over 1700 TWh produced by wind energy in 2020 and 3500 TWh in 2030. Depending on demand-side development, this would supply 7.3–8.2 per cent of global electricity demand in 2020 and 11.9–14.6 per cent in 2030.

ADVANCED SCENARIO

In the advanced wind energy scenario, an even more rapid expansion of the global wind power market is envisaged. The assumed growth rate starts at 27 per cent in 2008, falls to 22 per cent by 2010, then to 12 per cent by 2020 and 5 per cent by 2030.

The result is that by the end of this decade, global capacity reaches 186 GW, with annual additions of around 36.5 GW. By 2020, global capacity is over 1000 GW, with annual additions of around 142 GW, and by 2030, the total wind generation capacity reaches almost 2400 GW. The annual market then stabilises at around 165 GW.

In terms of generated electricity, this translates into 2600 TWh produced by wind energy in 2020 and 5700 TWh in 2030. Again depending on the increase in demand by that time, wind power would cover 11.2–12.6 per cent of global electricity demand in 2020 and as much as 19.7–24.0 per cent in 2030 – in other words meeting between a fifth and a quarter of the world's electricity needs.

REGIONAL BREAKDOWN

All three scenarios for wind power are broken down into geographical regions based on the methodology used by the IEA. For the purposes of this analysis, the regions are defined as Europe, the transition economies, North America, Latin America, China, India, the Pacific (including Australia, South Korea and Japan), developing Asia (the rest of Asia), and the Middle East and Africa.

This breakdown of world regions has been used by the IEA in the ongoing series of World Energy Outlook publications. We chose to use it here in order to facilitate comparison with the IEA projections and because the IEA provides the most comprehensive global energy statistics.

The level of wind power capacity expected to be installed in each region of the world by 2020 and 2030 is shown in Figures VI.6.1 to VI.6.3. These show that Europe would continue to dominate the world market under the least ambitious reference scenario. By 2030, Europe would still have 46 per cent of the global wind power market, followed by North America with 27 per cent. The next largest region would be China with 10 per cent.

The two more ambitious scenarios envisage much stronger growth in regions outside Europe. Under the moderate scenario, Europe's share will be 23 per cent by 2030, with North America dominating the global market at 27 per cent and major contributions coming from China (14 per cent), India (10 per cent) and developing Asia (10 per cent). Latin America (7 per cent) and the Pacific region (5 per cent) will play a smaller role than previously estimated.

The advanced scenario predicts an even stronger growth for China, which would see its share of the world market increasing to 19 per cent by 2030. The North American market accounts for 22 per cent of global wind power capacity, whilst Europe's share is 15 per cent, followed by India (10 per cent), developing Asia (9 per cent), the Pacific region (9 per cent) and Latin America (8 per cent). In both scenarios, Africa and the Middle East would play only a minor role in the timeframe discussed (1 per cent of global capacity in the moderate and 2 per cent in the advanced scenario).

In all three scenarios it is assumed that an increasing share of new capacity is accounted for by the replacement of old power plants. This is based on a wind turbine average lifetime of 20 years. Turbines replaced within the timescale of the scenarios are assumed to be of the same cumulative installed capacity as the original smaller models. The result is that an increasing proportion of the annual level of installed capacity will come from repowered turbines. These new machines will contribute to the overall level of investment, manufacturing output and employment. As replacement turbines, their introduction will not, however, increase the total figure for global cumulative capacity.

The German Aerospace Centre

The German Aerospace Centre (DLR) is the largest engineering research organisation in Germany. Among its specialities are the development of solar thermal power station technologies, the utilisation of low- and high-temperature fuel cells, particularly for electricity generation, and research into the development of high-efficiency gas and steam turbine power plants.

The Institute of Technical Thermodynamics at the DLR (DLR-ITT) is active in the field of renewable energy research and technology development for efficient and low-emission energy conversion and utilisation. Working in cooperation with other DLR institutes, industry and universities, research is focused on solving key problems in electrochemical energy technology and solar energy conversion. This encompasses application-orientated research, the development of laboratory and prototype models, and the design and operation of demonstration plants. System analysis and technology assessment are used to help prepare strategic decisions in the field of research and energy policy.

Within the DLR-ITT, the System Analysis and Technology Assessment Division has long-term experience in the assessment of renewable energy technologies. Its main research activities are in the field of techno-economic utilisation and system analysis, leading to the development of strategies for the market introduction and dissemination of new technologies, mainly in the energy and transport sectors.

Scenario Background

The DLR was commissioned by Greenpeace International and EREC to conduct a study on global sustainable energy pathways up to 2050. This so-called 'Energy revolution' scenario published in early 2007 is a blueprint on how to cut global CO_2 emissions by 50 per cent by 2050, while maintaining global economic growth. Part of the study examines the future potential for renewable energy sources; together with input from the wind energy industry and analysis of regional projections for wind power around the world, it forms the basis of the Global Wind Energy Outlook scenario.

Part VI Notes

1 See EWEA report, 'Pure power: Wind energy scenarios up to 2030', EWEA, March 2008.

2 Renewable Energy Roadmap, COM(2006)848 final, European Commission.

3 Renewable Energy Roadmap – Impact Assessment, SEC(2006)1720, European Commission.

4 West Texas Intermediate.

5 See: http://ec.europa.eu/energy/energy_policy/doc/03_renewable_energy_roadmap_en.pdf.

WIND ENERGY - THE FACTS

APPENDICES

APPENDIX A: ONSHORE WIND MAPS

EUROPE

Figure A.1: European wind atlas

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	
	m/s	W/m^2	m/s	W/m^2	m/s	W/m^2	m/s	W/m^2	m/s	W/m^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

DENMARK

Figure A.2: Denmark wind atlas

Source: [2] in the list of references

FINLAND

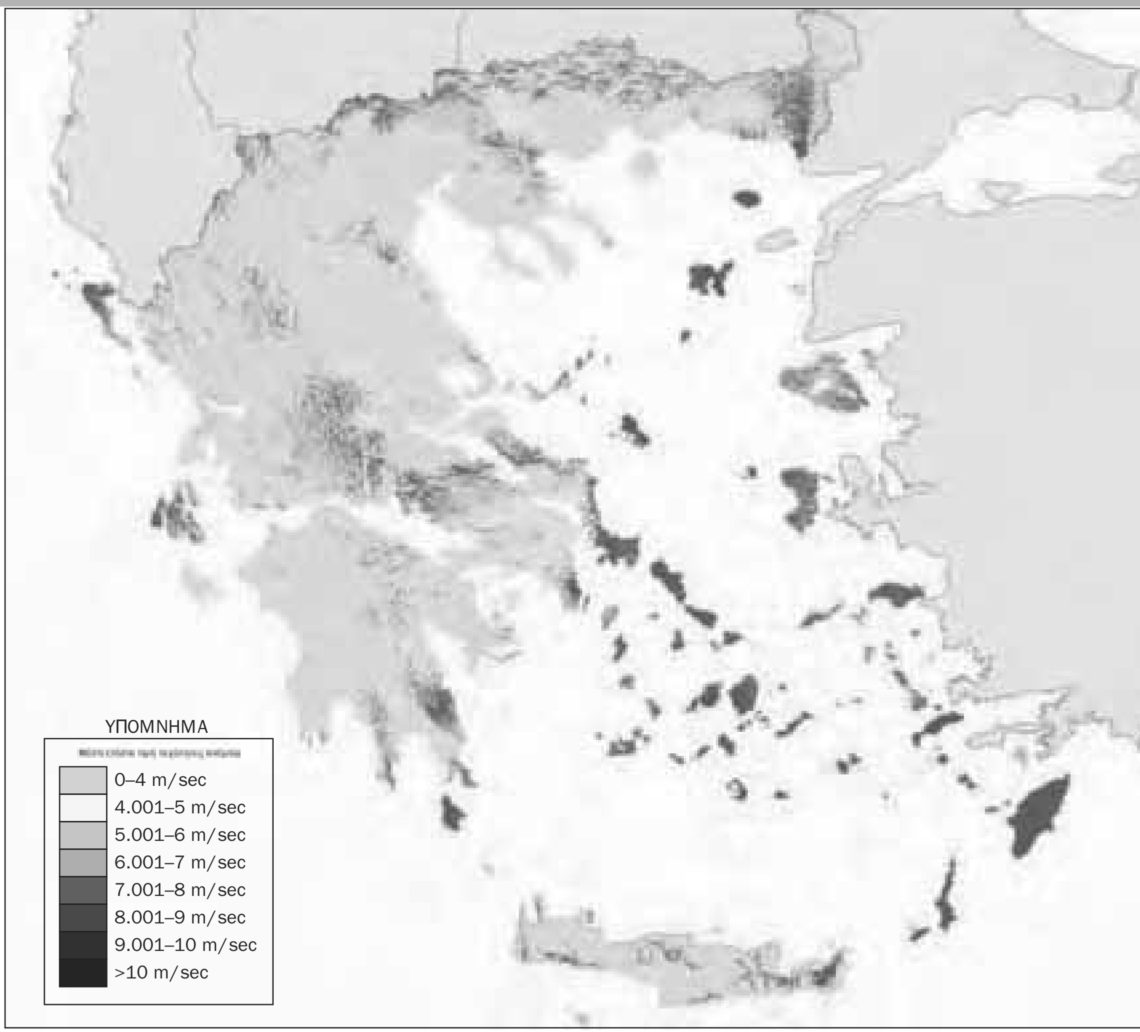
Figure A.3: Finland wind atlas

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	
	m/s	W/m^2	m/s	W/m^2	m/s	W/m^2	m/s	W/m^2	m/s	W/m^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: [4] in the list of references

GREECE

Figure A.4: Greece wind atlas



Source: [6] in the list of references

IRELAND

Figure A.5: Ireland wind atlas

Source: [8] in the list of references

UK

Figure A.6: UK wind atlas

NOABL-Wind resources at 45 m above ground level

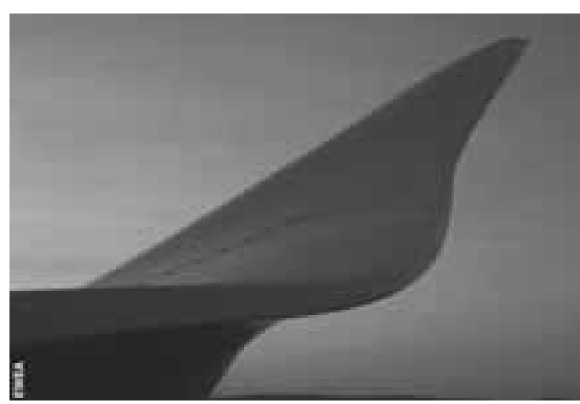
<5.0 m/s	5.0–6.0	6.0–7.0	7.0–8.0
100.0 m/s	8.0–9.0	9.0–10.0	

Source: [12] in the list of references

CENTRAL EUROPEAN COUNTRIES

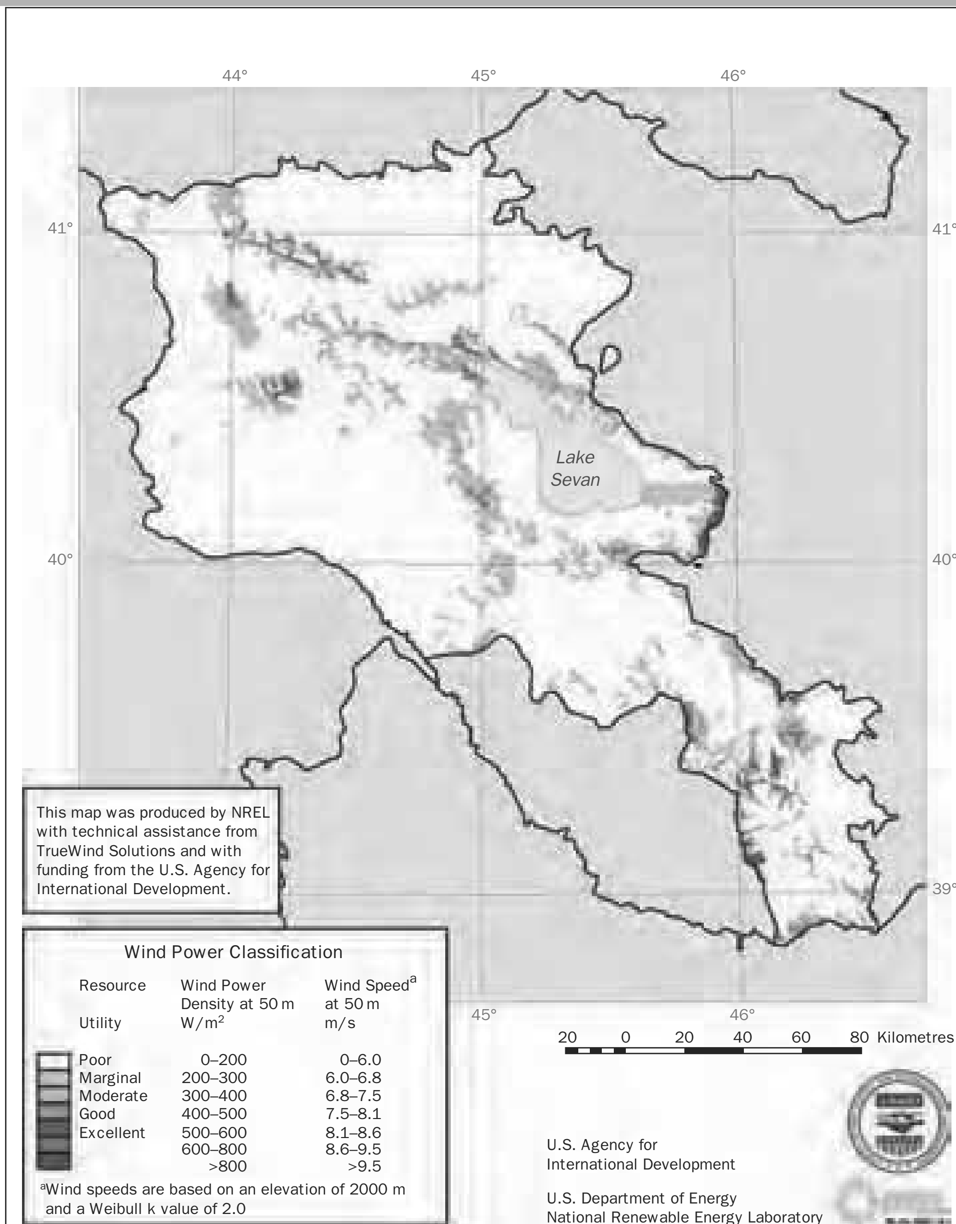
Figure A.7: Central European wind atlas

Source: [1] in the list of references



ARMENIA

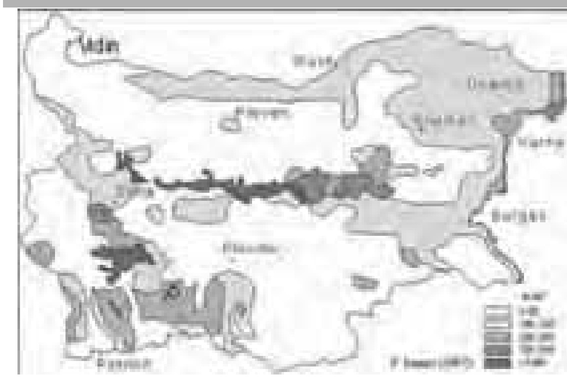
Figure A.8: Armenia wind atlas



Source: [22] in the list of references

BULGARIA

Figure A.9: Bulgaria wind atlas



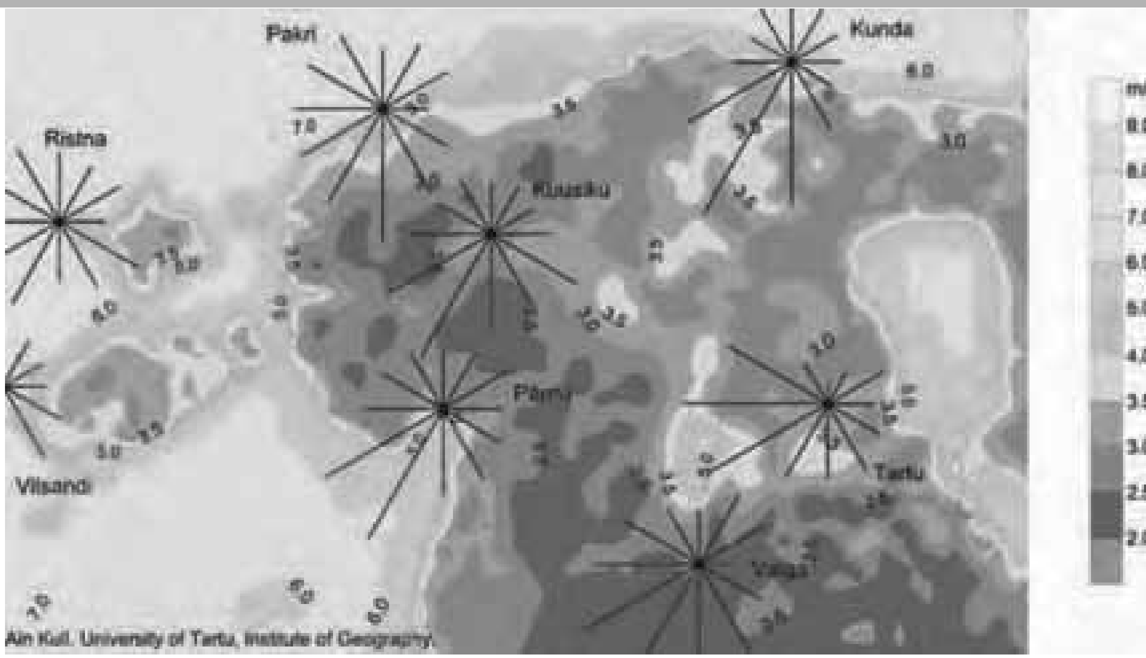
Source: [14] in the list of references

ESTONIA

Figure A.10: Estonia wind atlas

Source: [15] in the list of references

Figure A.11: Estonia wind atlas



Source: [16] in the list of references

RUSSIA

Figure A.12: Russian wind atlas

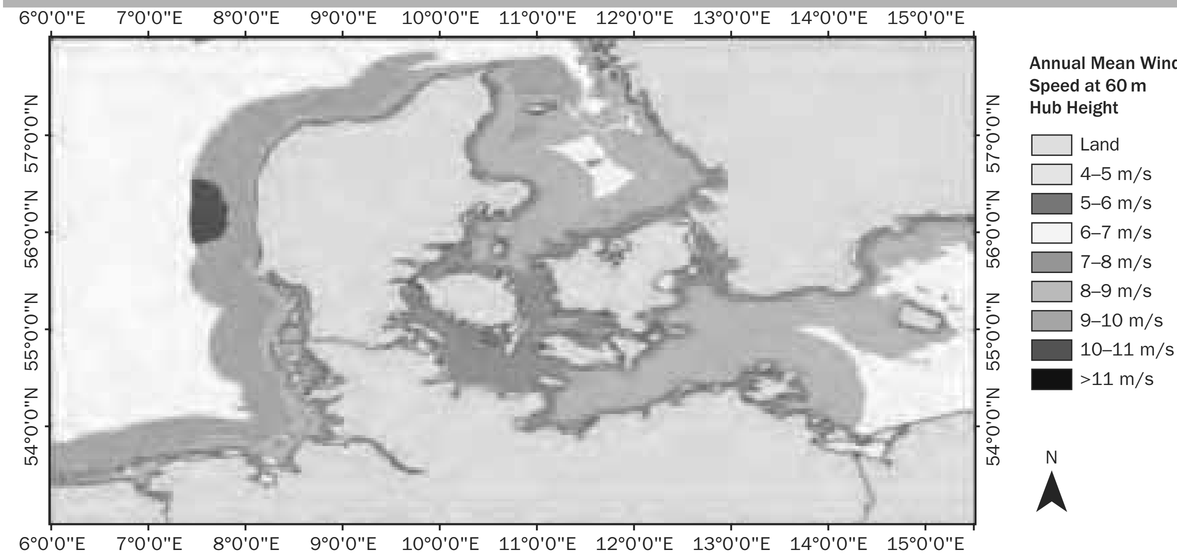
Wind resources at the height of 50 metres above ground level for five different topographic conditions

	Sheltered terrain		Open terrain		Sea coast		Open sea		Hills and ridges	
	m/s	W/m^2	m/s	W/m^2	m/s	W/m^2	m/s	W/m^2	m/s	W/m^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: [24] in the list of references

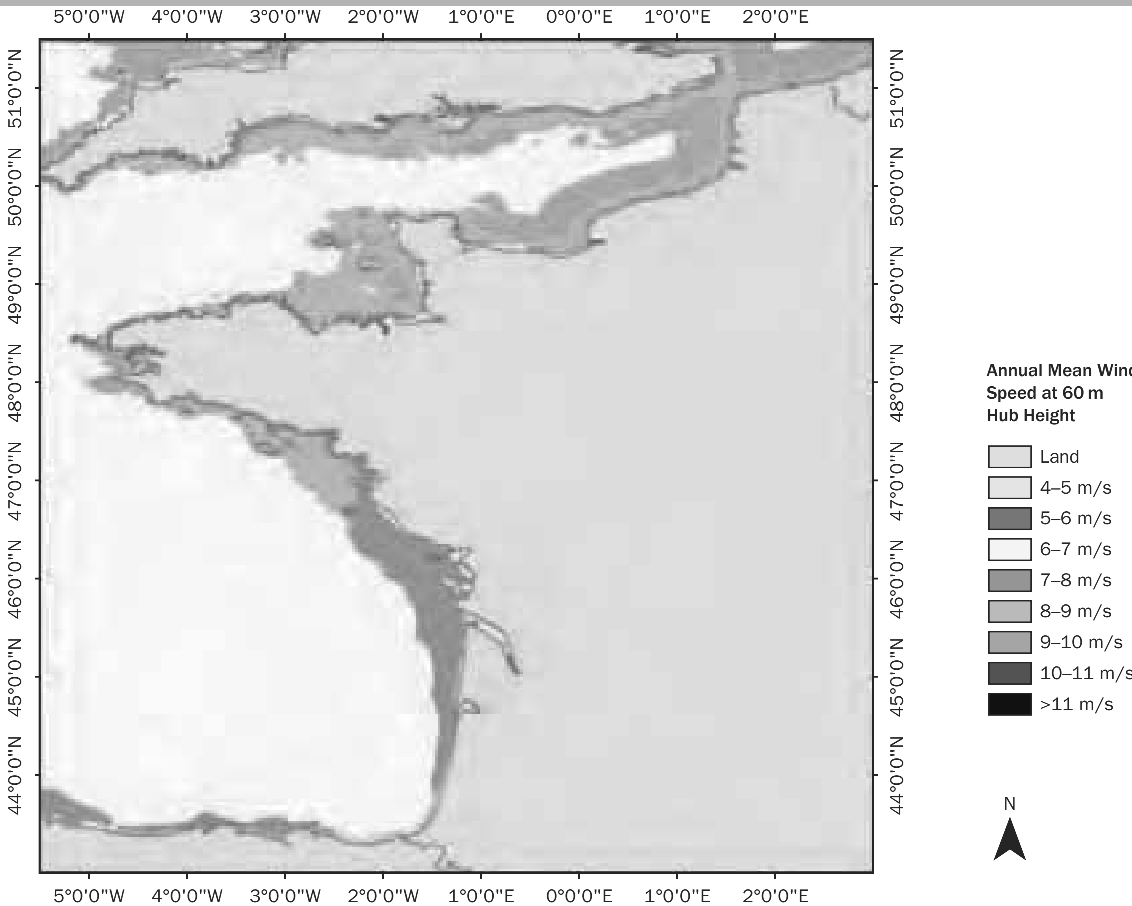
APPENDIX B: OFFSHORE WIND SPEEDS MODELLED IN 'STUDY OF OFFSHORE WIND ENERGY IN THE EC'

Figure B.1: Denmark and Germany



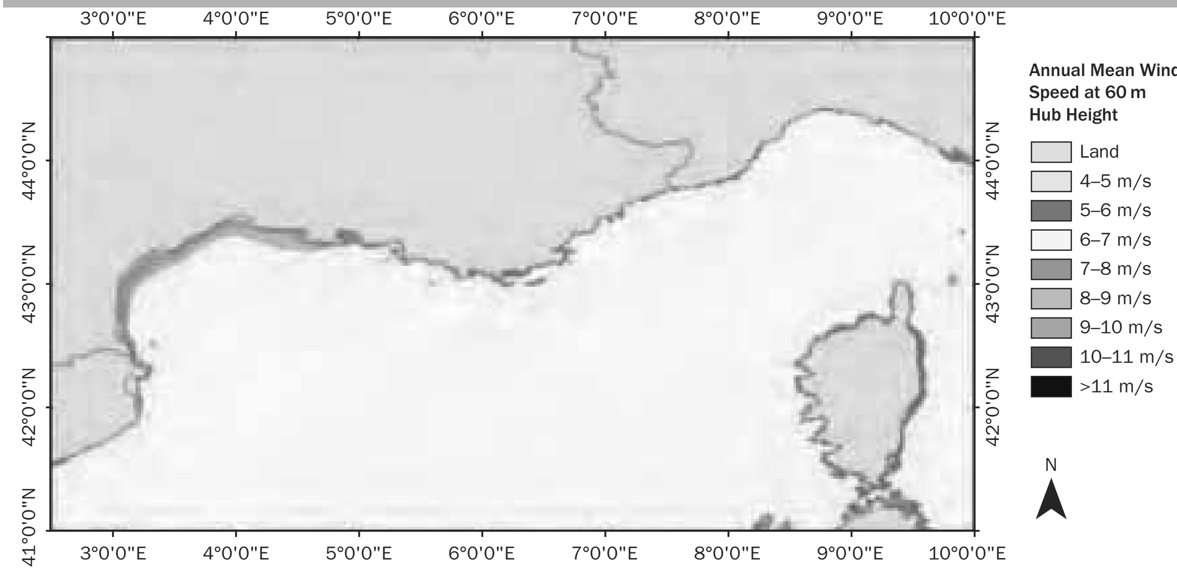
Source: Matthies and Garrad (1993)

Figure B.2: France – Atlantic



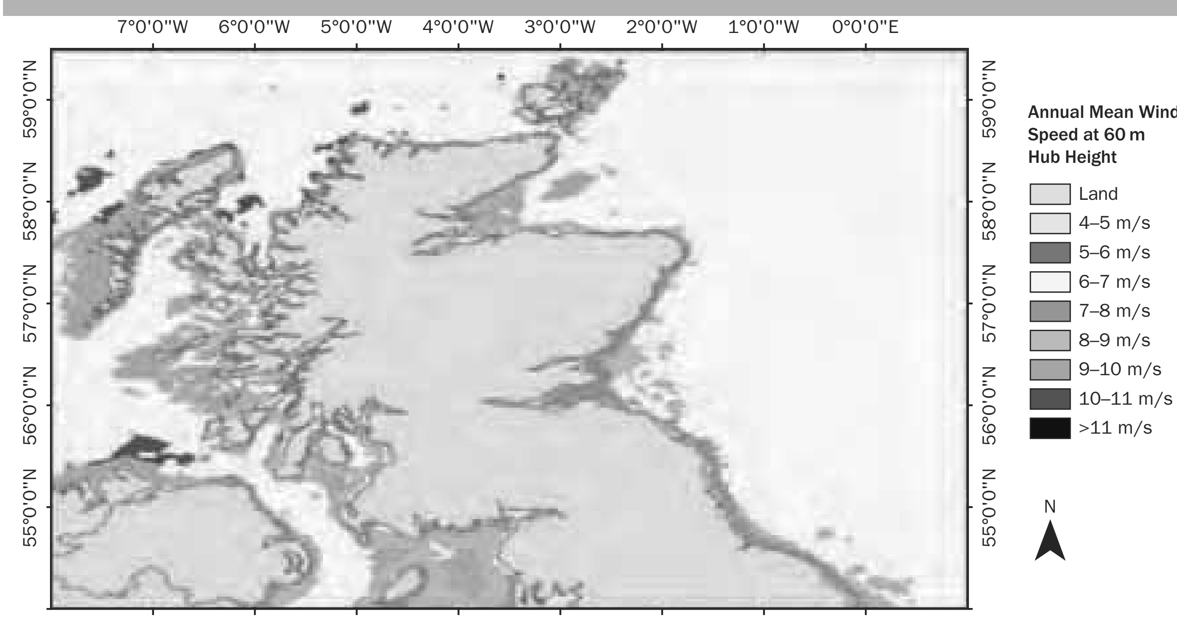
Source: Matthies and Garrad (1993)

Figure B.3: France – Mediterranean



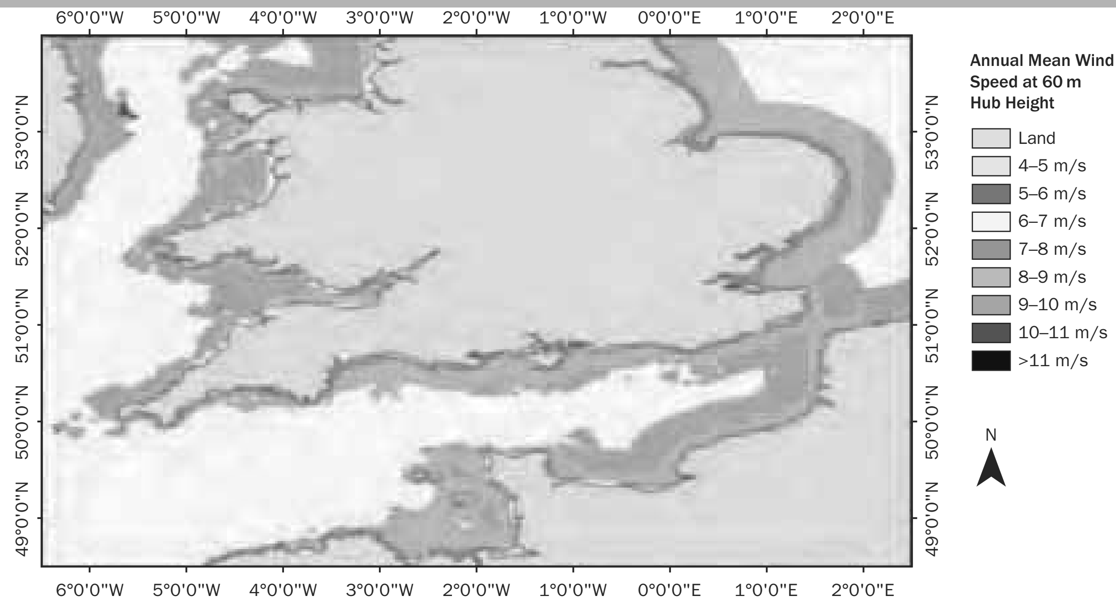
Source: Matthies and Garrad (1993)

Figure B.4: Great Britain – North



Source: Matthies and Garrad (1993)

Figure B.5: Great Britain – South

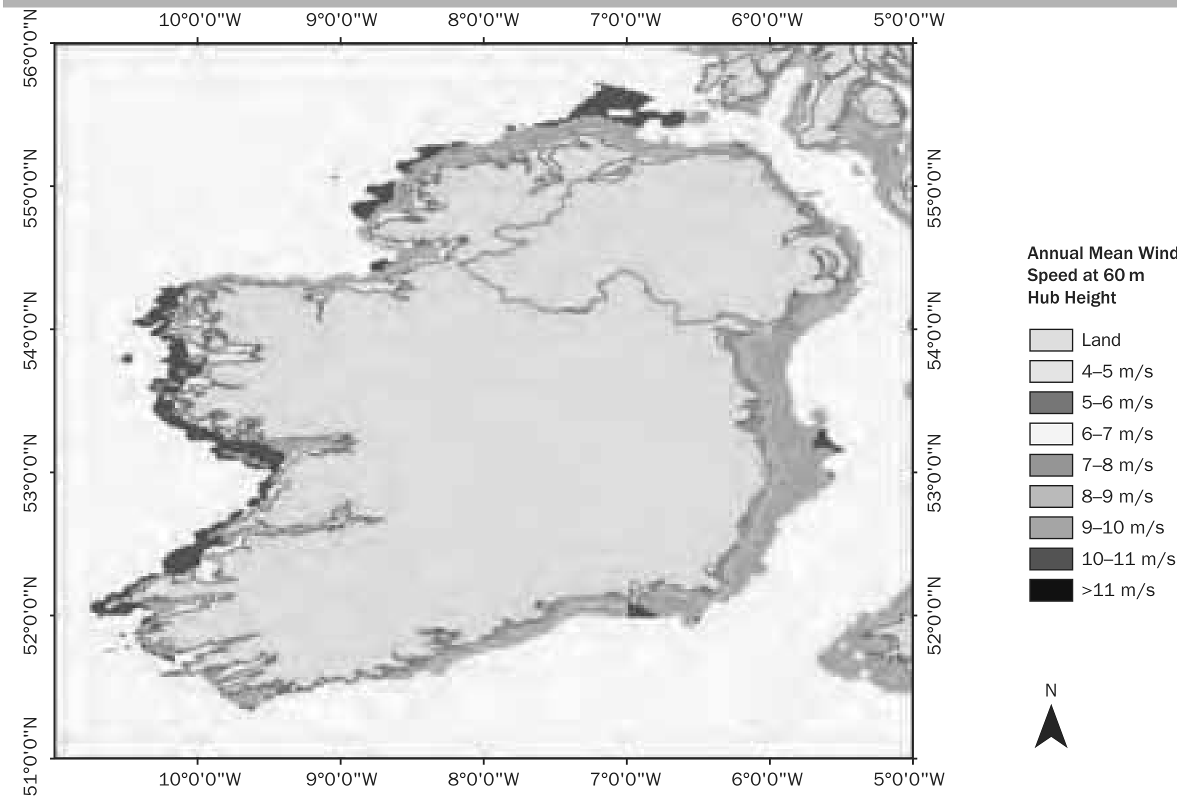


Source: Matthies and Garrad (1993)

Figure B.6: Greece

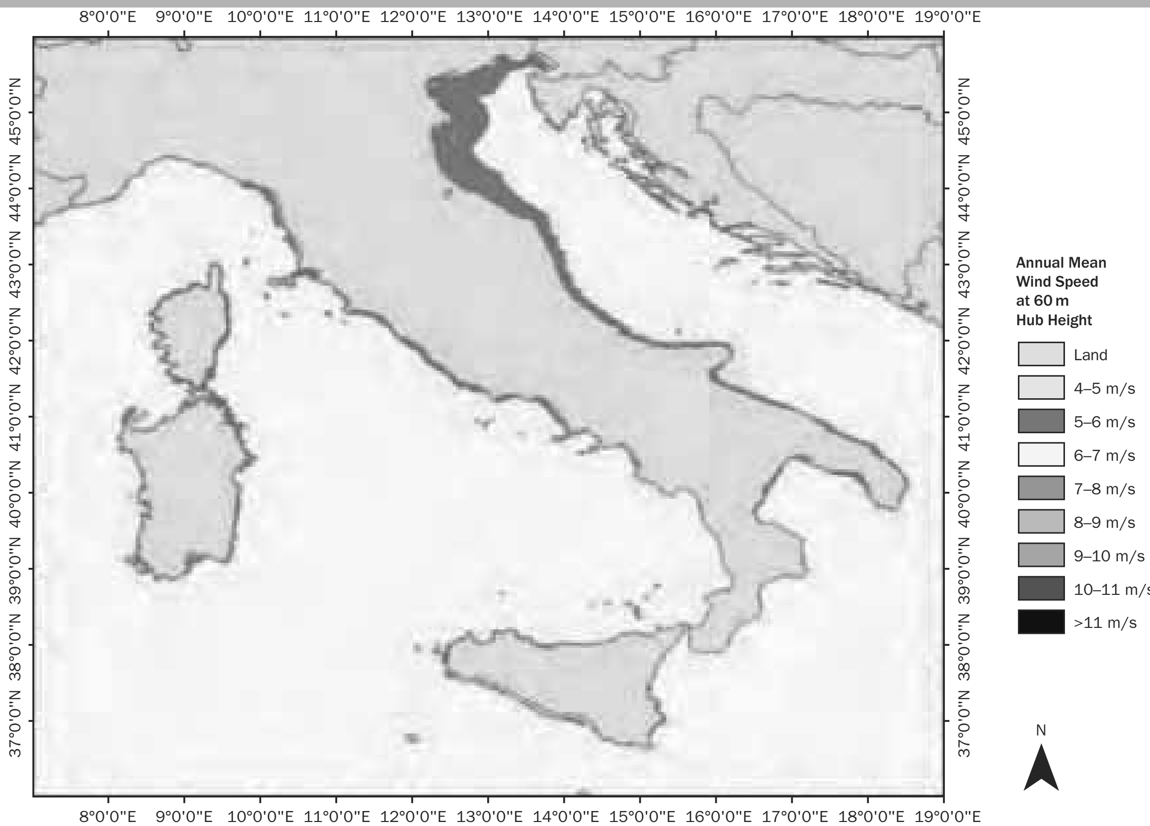
Source: Matthies and Garrad (1993)

Figure B.7: Ireland



Source: Matthies and Garrad (1993)

Figure B.8: Italy

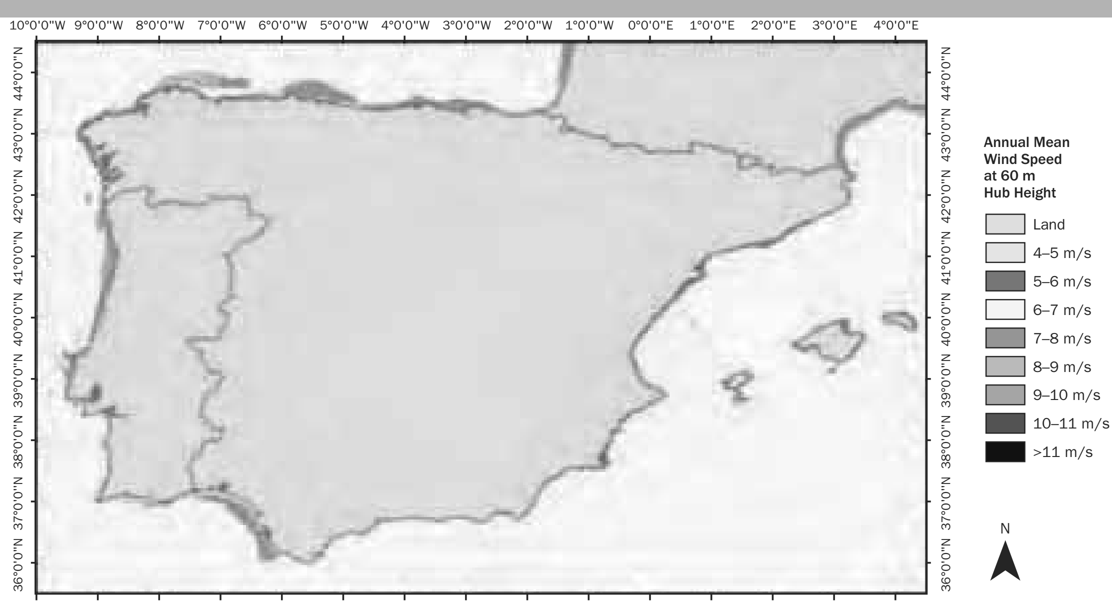


Source: Matthies and Garrad (1993)

Figure B.9: The Netherlands and Belgium

Source: Matthies and Garrad (1993)

Figure B.10: Spain and Portugal



Source: Matthies and Garrad (1993)

APPENDIX C: WORKED EXAMPLE FOR CULLIAGH WIND FARM, IRELAND

Introduction

The main text has provided a general discussion of the assessment of the wind resource and energy production. This appendix is included in order to provide a 'worked example'. It demonstrates all the different aspects of the process outlined in the main text. The project considered is the Culliagh Wind Farm in Ireland, which consists of 18 Vestas V47 wind turbines and was constructed in 2000. The following specific analyses are presented:

1. the results of the pre-construction projection of the expected energy production of the wind farm, including uncertainty analysis;
2. the review of the actual production of the wind farm over a 17-month period; and
3. the results of a 'wind in–energy out' validation test of the predictive methodologies employed in (1).

Airtricity, a leading international wind farm developer, owns the Culliagh Wind Farm and thanks are to be extended to them for allowing their proprietary data to be used for this case study. A photograph of the wind farm is presented in Figure C.1

Description of the Site and Monitoring Equipment

The location of the site is shown in Figure C.2. The site lies in central County Donegal approximately 14 km southwest of Letterkenny. The location of Malin Head Meteorological Station is also marked on the figure. The wind farm site lies on Culliagh Mountain with maximum elevation of approximately 360 m, as shown in Figure C.3.

The site at Culliagh Mountain has had one 30 m and two 10 m temporary meteorological masts installed since mid-1997. The 10 m data is not considered further in this report.

The wind data from the 30 m site mast have been recorded using NRG sensors with a maximum of 40 anemometer and wind vane at 10 m and 30 m. An NRG 9210 logger was programmed to record hourly mean wind speed, wind speed standard deviation, 3-second gust and direction.

Malin Head Meteorological Station

The assessment of the wind climate at the site uses data recorded at a nearby meteorological station, Malin Head, which is situated on the coast approximately 65 km north-northeast of the Culliagh site. From discussions with Met Éireann (the Irish meteorological service) staff and consideration of other meteorological stations in the region, it was concluded that Malin Head was the most appropriate reference meteorological station for this analysis. Data from 1979 to 2000 have been used in the analysis reported here. Discussions with Met Éireann staff indicate that there has been no change during this period which will have a significant effect on the consistency of the measurements. This is important since the analysis method used here relies on long-term consistency of the

Figure C.1: The Culliagh Wind Farm

Figure C.2: Location of the proposed Culliagh Mountain Wind Farm and Malin Head Meteorological Station

measurements at the meteorological station. The location of the Malin Head Meteorological Station is presented in Figure C.4 and a photograph of the meteorological mast is presented in Figure C.5.

Wind Data

The data sets from Malin Head and the Culliagh site, as used in the analyses described in the following sections, are summarised in Table C.1.

Description of the Proposed Wind Farm

The wind turbine model selected for the proposed Culliagh Mountain Wind Farm is the Vestas V47 660 kW model with a hub height of 45 m. The basic parameters of the turbine are presented in Table C.2.

The power curve used in the analysis has been supplied for an air density of 1.225 kg/m^3 and is presented in Table C.3.

From data recorded at local meteorological stations and with standard lapse rate assumptions, the Culliagh Mountain site is predicted to have an air density of 1.205 kg/m^3. Since the predicted mean air density at the site differs from the air density for which the power curves were supplied, a small air density adjustment following IEC 61400-12:1998 was made to the power curves used in the analysis.

The power curve for the Vestas V47 660 kW turbine has been compared to a reference curve from an independent test of the performance of the turbine. It was found that the reference curve outperformed the supplied curve by 2 per cent for the wind regime at the Culliagh site. This result indicates that the supplied

Figure C.3: The Culliagh Mountain site

curve is broadly in line with the performance that may be expected.

The proposed Culliagh Wind Farm is designed to have a total nameplate capacity of just under 12 MW. The wind farm layout has been supplied by the client and the layout is presented in Figure C.6. Also shown in Figure C.6 are the locations of the meteorological masts.

The Culliagh Mountain Wind Farm is located approximately 1.5 km south of the existing Cark Wind Farm. The effect of these turbines on the predicted energy production of the Culliagh development was also estimated.

Results of the Analysis

The analysis to determine the wind regime and expected energy production of the proposed Culliagh Wind Farm involved several steps:

- the directional correlations between wind speeds recorded at Culliagh Mast 05 at 30 m and at Malin Head were established;
- the correlation relationships were applied to historical wind data recorded at Malin Head to produce a description of the long-term wind regime at Culliagh Mast 05;

Figure C.4: Area surrounding the Malin Head Meteorological Station

- wind flow modelling was carried out to determine the hub height wind speed variations over the site relative to the 30 m anemometry mast;
- the energy production of the wind farm was calculated, taking account of array losses and topographic effects;
- the seasonal variation in the energy production of the wind farm was calculated; and
- sources of uncertainty in the wind speed and energy production estimates were identified and quantified.

Correlation of Wind Regime at Culliagh Mountain and Malin Head

The measured wind direction at Culliagh Mast 05 at 30 m is compared to the concurrent wind direction measured at Malin Head in Figure C.7. The directions recorded between the two locations show some scatter but are generally well correlated for the most frequent sectors.

The monitored wind speeds at 30 m height in each of twelve 30-degree direction sectors are compared to the concurrent wind speed at Malin Head in Figure C.8. The quality of the correlation is considered to be reasonable for all direction sectors. The wind speed ratios for each direction sector are presented in Table C.4.

Long-Term Mean Wind Speed at Culliagh Mountain

The wind speed ratios listed in Table C.4 were used to factor the long-term wind speeds at Malin Head for the period 1979 to 1998. By this method, the long-term

Figure C.5: The Malin Head anemometry tower

mean wind speed at Culliagh Mast 05 at 30 m was calculated to be 7.2 m/s.

The corresponding joint wind speed and direction frequency distribution for Culliagh Mast 05 over the historical period 1979 to 1998 is presented in Figure C.9 in the form of a wind rose.

Site Wind Speed Variations at Culliagh Mountain

The variation in wind speed over the Culliagh Mountain site has been predicted using the WAsP computational flow model, details of which are given in the appendix to the study. WAsP was used to model the wind flow over the site, being initiated from the long-term wind speed and direction frequency distribution derived for Mast 05 at 30 m.

Table C.5 shows the predicted long-term mean wind speed at each wind turbine location at hub height. The average long-term mean wind speed at a hub height of 45 m for the whole wind farm was found to be 8.1 m/s.

Projected Energy Production

The energy production for each of the wind farm layouts is detailed in Table C.6 (the energy capture of individual turbines is given in Table C.5).

The energy production predictions include calculation of the array and topographic effects, an estimate of availability and electrical loss and factors to account for wind turbine icing, high wind hysteresis and the wake effect of existing turbines. Other potential

Table C.1: Data available from Culliagh and from Malin Head

Culliagh Mountain Mast 05 (206940, 402500)	Hourly mean wind speed, standard deviation, gust and direction at 30 m.	5 July 1997–24 January 1999
	Hourly mean wind speed, standard deviation and direction at 10 m.	
Malin Head Meteorological Station (241950, 458550)	Hourly record of ten-minute mean wind speed and direction (time series data).	May 1997–January 2000
	Hourly record of ten-minute mean wind speed and direction (frequency table).	1979–1998

Table C.2: Main parameters of the Vestas V47 660 kW wind turbine

Diameter	47.0 m
Hub height	45.0 m
Rotor speed	28.5 rpm
No of blades	3
Nominal rated power	660 kW

sources of energy loss are also listed. It is recommended to carefully reconsider these issues, since at the time of this energy assessment there was insufficient information to estimate the effect on the predicted energy production.

Table C.3: Performance data for the Vestas V47 660 kW wind turbine

Wind speed (m/s at hub height)	V47 power output (kW)
4	2.9
5	43.8
6	96.7
7	166
8	252
9	350
10	450
11	538
12	600
13	635
14	651
15	657
16	659
17	660
18	660
19	660
20	660
21	660
22	660
23	660
24	660
25	660

Figure C.6: Layout of the proposed Culliagh Wind Farm

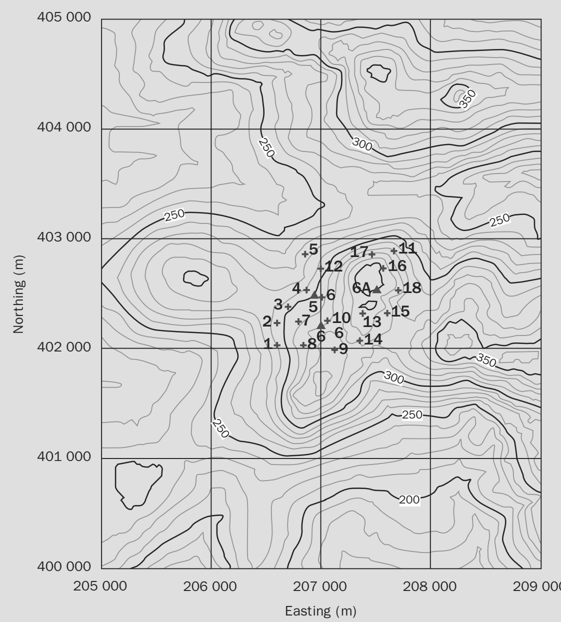


Figure C.7: Correlation of wind direction at Malin Head and at Culliagh Mast 05 at 10 m

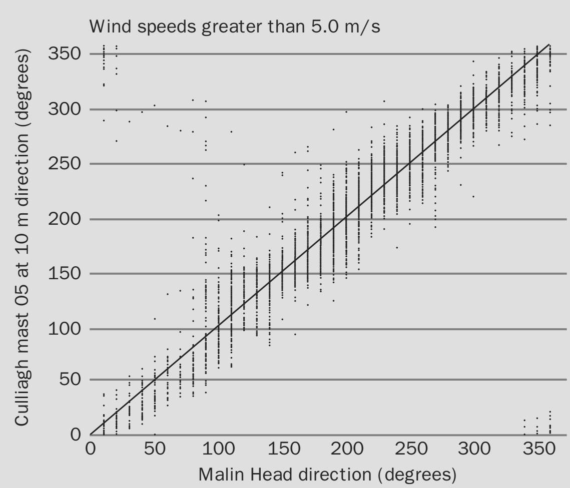
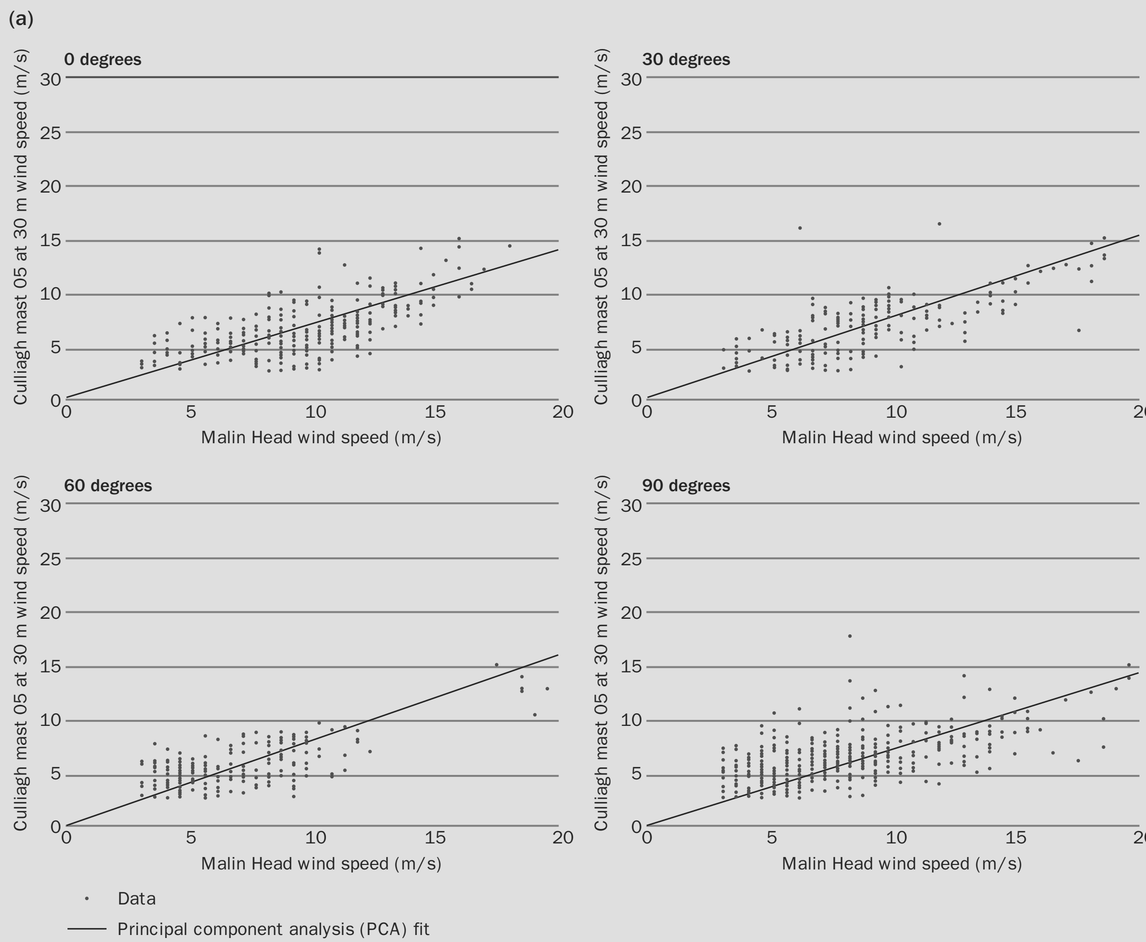


Figure C.8: Correlation of wind speed at Malin Head and at Culliagh Mast 05 at 30 m



Seasonal Variations

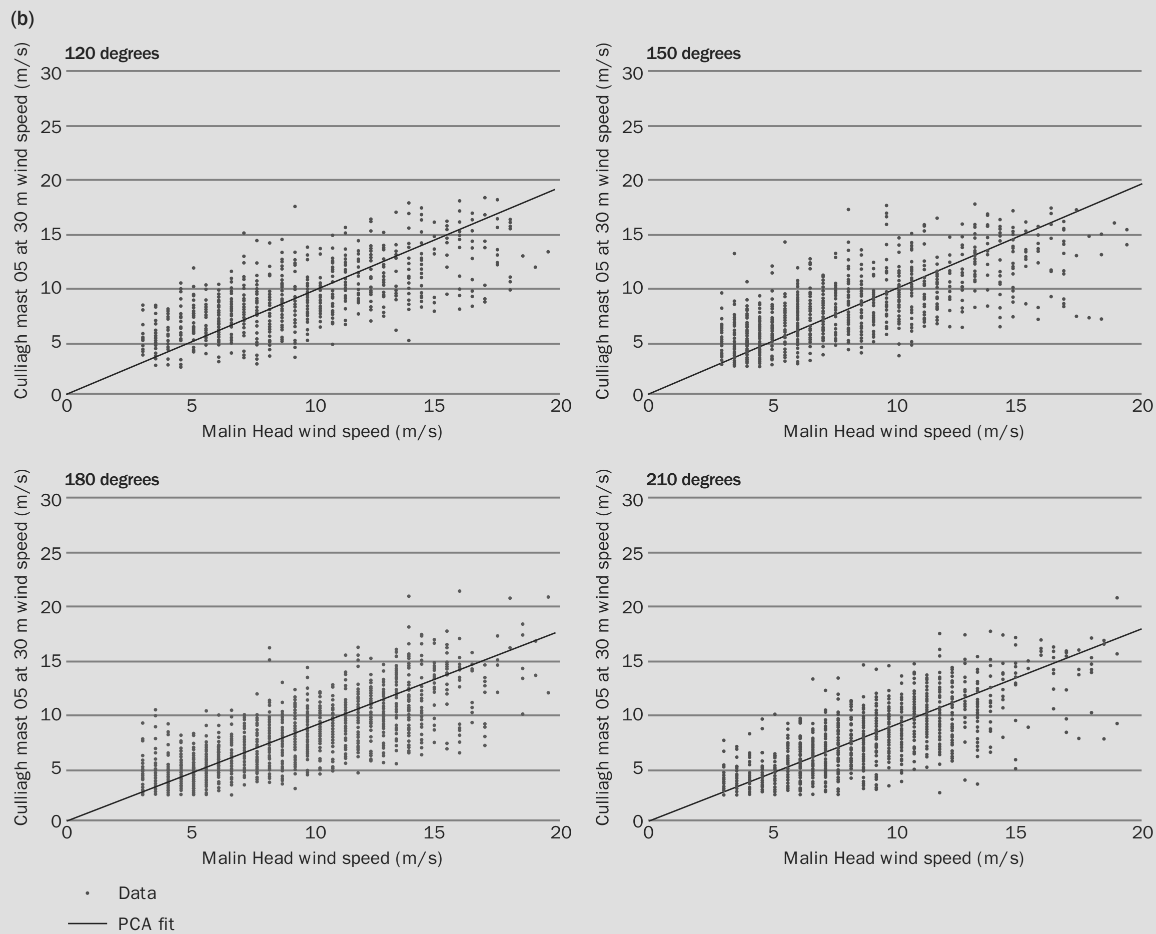
The monthly energy production of the wind farm is presented in Table C.7. There is a large seasonal variation of the predicted long-term monthly energy production, with winter and summer months producing approximately 140 per cent and 60 per cent, respectively, of the long-term mean monthly energy production.

Uncertainty Analysis

The main sources of deviation from the central estimate have been quantified and are shown in Tables C.8a and Table C.8b, which consider future periods of ten years and one year, respectively.

The figures in these tables, when added as independent errors, give the following uncertainties in net energy production: 4.5 GWh/annum for a future

Figure C.8: Correlation of wind speed at Malin Head and at Culliagh Mast 05 at 30 m – Continued

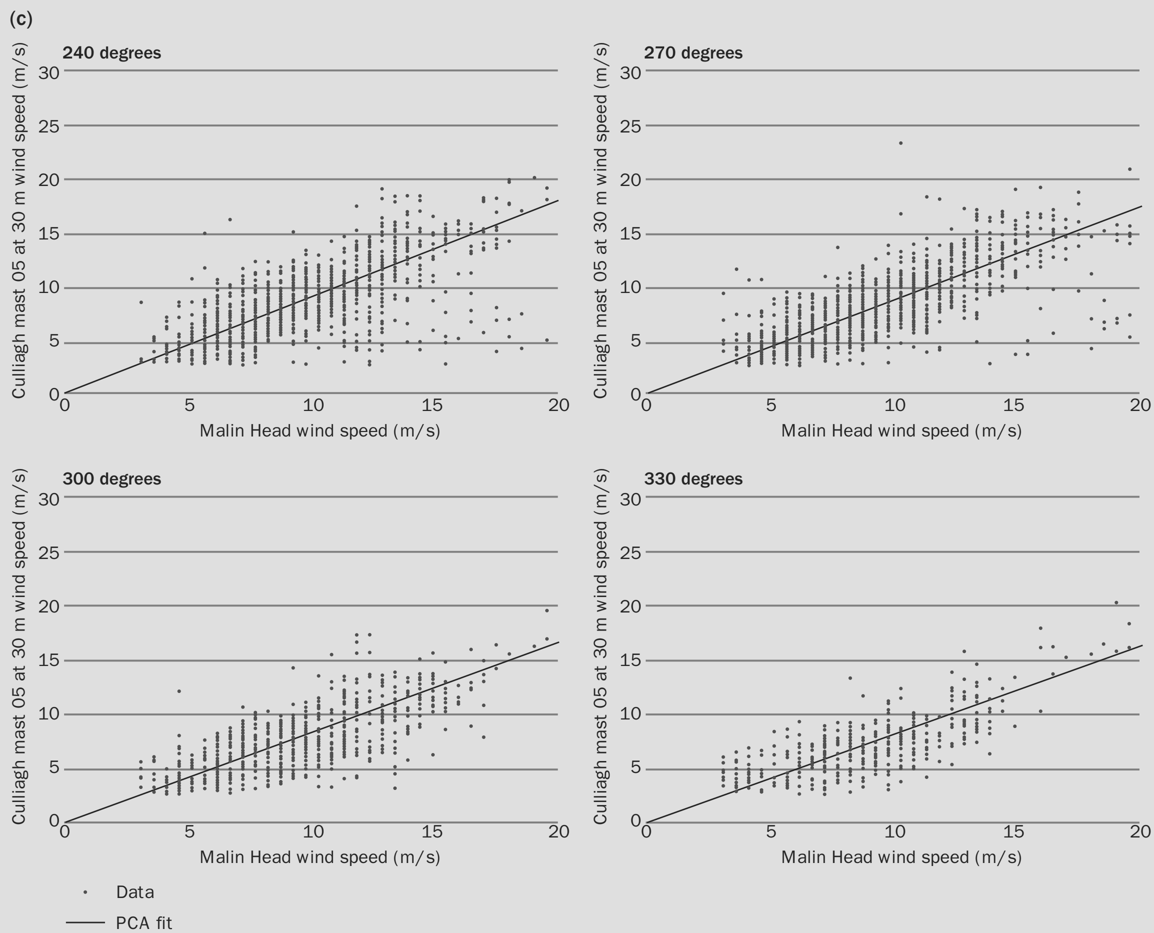


one-year period and 2.7 GWh/annum for a future ten-year period. The detailed derivation of the above uncertainties is presented below.

There are four main categories of uncertainty associated with the site wind speed prediction at Culliagh Mountain:

1. There is an uncertainty associated with the measurement accuracy of the site anemometers. The instruments used on this site have not been individually calibrated to MEASNET standards and a consensus calibration has been applied. Batch calibration of NRG Maximum 40 anemometers have shown them to conform to the consensus calibration to within 1.5 per cent. Therefore a figure of 2 per cent is assumed here so as to account for other second-order effects such as over-speeding, degradation, air density variations and sensor mounting. No allowance has been made for uncertainty in the Malin Head anemometer, as consistency and not absolute accuracy is important.
2. An error analysis was carried out on the correlation for each direction sector and from this the standard

Figure C.8: Correlation of wind speed at Malin Head and at Culliagh Mast 05 at 30 m – Continued



error for the long-term mean wind speed was determined. This was carried out for the correlation between Malin Head and Culliagh Mountain.

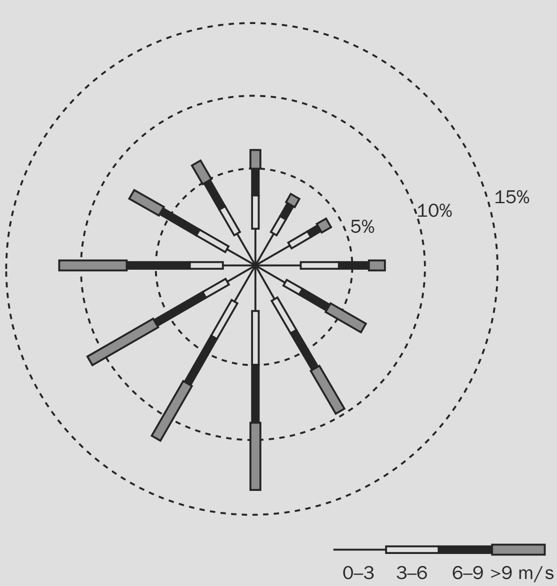
3. There is an uncertainty associated with the assumption made here that the historical period at the meteorological site is representative of the climate over longer periods. A study of historical wind records from a number of reference stations indicates an average variability of 6 per cent in the annual mean wind speed. This figure is used to define the uncertainty in assuming the long-term mean wind speed is defined by a period 20 years in length.
4. For a finite number of future years, the mean wind speed may differ from the long-term mean due to the natural variability of a random process. Account is taken of the future variability of wind speed in the energy confidence analysis but not the wind speed confidence analysis.

It is assumed that the time series of wind speed is random with no systematic trends. Care was taken to

Table C.4: Wind speed ratios between Culliagh Mast 05 at 30 m and Malin Head

Direction sector	Number of hours analysed	Wind speed ratio
345–15	278	0.701
15–45	194	0.767
45–75	229	0.800
75–105	461	0.718
105–135	795	0.957
135–165	1098	0.976
165–195	1622	0.879
195–225	1208	0.897
225–255	1210	0.894
255–285	1230	0.868
285–315	708	0.834
315–345	421	0.819
All	9454	0.861

Figure C.9: Annual wind rose for Culliagh Mast 05 at 30 m



ensure that consistency of the Malin Head measurement system and exposure has been maintained over the historical period and no allowance is made for uncertainties arising due to changes in either.

Uncertainties type (1), (2) and (3) above are added as independent errors on a root-sum-square basis to give the total uncertainty in the site wind speed prediction for the historical period considered.

It is considered here that there are four categories of uncertainty in the energy output projection:

1. Long-term mean wind speed-dependent uncertainty is derived from the total wind speed uncertainty (types (1), (2), (3) and (4) above), using a factor for the sensitivity of the annual energy output to

Table C.5: Mean wind speed and projected energy output of individual wind turbines

Turbine number	Mean hub height wind speed[1] (m/s)	Energy output[2] (GWh/annum)
1	7.7	2.2
2	7.8	2.1
3	7.8	2.1
4	7.6	1.9
5	7.4	2.0
6	7.8	2.0
7	8.0	2.1
8	8.1	2.3
9	8.4	2.5
10	8.0	2.2
11	8.2	2.3
12	7.6	2.0
13	8.6	2.4
14	8.2	2.3
15	8.2	2.3
16	8.8	2.5
17	8.5	2.4
18	8.3	2.3
Overall	8.1	

Notes: [1]Wind speed at location of turbines at 45 m height, not including wake effects; [2]Individual turbine output includes topographic and array effects only.

Table C.6: Predicted energy production of Culliagh Mountain Wind Farm

Ideal energy production	40.2	GWh/annum
Topographic effect	107.0%	Calculated
Array effect	92.7%	Calculated
Electrical transmission efficiency	97.0%	Estimate
Availability	97.0%	Estimate
Icing and blade fouling	99.0%	Estimate
High wind hysteresis	99.6%	Estimate
Substation maintenance	100.0%	Not considered
Utility downtime	100.0%	Not considered
Power curve adjustment	100.0%	Not considered
Columnar control losses	100.0%	Not considered
Wake effect of existing wind farms	99.8%	Estimate
Net energy production	36.9	GWh/annum

Table C.8a: Uncertainty in projected energy output of the proposed wind farm – Ten-year future period

	Wind speed		Energy output[1]	
Source of uncertainty	**(%)**	**(m/s)**	**(%)**	**(GWh/annum)**
Anemometer accuracy	2.0	0.14		=
Correlation accuracy		0.19		
Period representative of long-term	1.3	0.10		
Total wind		**0.26**		**2.22**
Wake and topographic calculation	n/a	n/a	3.0	1.11
Wind variability (10 years)	1.9	0.14		1.19
Overall (10 years)				**2.75**

Note: [1]Sensitivity of net production to wind speed is calculated to be 8.68 GWh/annum/(m/s).

changes in annual mean wind speed. This sensitivity is derived by a perturbation analysis about the central estimate.

2. Wake and topographic modelling uncertainties. Validation tests of the methods used here, based on full-scale wind farm measurements made at small wind farms, have shown that the methods are accurate to 2 per cent in most cases. For this development, an uncertainty in the wake and topographic modelling of 3 per cent is assumed.

Table C.7: Monthly variation of the projected energy output of the wind farm

Month	**Energy output[1] (GWh)**
January	4.27
February	3.87
March	3.84
April	2.53
May	2.16
June	1.86
July	2.05
August	2.21
September	2.85
October	3.60
November	3.67
December	3.99

Note: [1]Energy output includes all losses.

Table C.8b: Uncertainty in projected energy output of the proposed wind farm – One-year future period

	Wind speed		Energy output[1]	
Source of uncertainty	**(%)**	**(m/s)**	**(%)**	**(GWh/annum)**
Anemometer accuracy	2.0	0.14		=
Correlation accuracy		0.19		
Period representative of long-term	1.3	0.10		
Total wind		**0.26**		**2.22**
Wake and topographic calculation	n/a	n/a	3.0	1.11
Wind variability (1 year)	6.0	0.43		3.75
Overall (1 year)				**4.49**

Note: [1]Sensitivity of net production to wind speed is calculated to be 8.68 GWh/annum/(m/s).

3. Future wind speed-dependent uncertainties described in (4) above have been derived using a factor for the sensitivity of the annual energy output to changes in annual mean wind speed. This sensitivity is derived by a perturbation analysis about the central estimate.
4. Turbine uncertainties are generally the subject of contract between the developer and turbine supplier and we have therefore made no allowance for them in this work.

Again those uncertainties which are considered are added as independent errors on a root-sum-square basis to give the total uncertainty in the projected energy output.

Summary of the Results of the Analysis

Wind data have been recorded at the Culliagh Mountain site for a period of 18 months. Based on the results from the analysis of these data, in combination with concurrent data and historical wind data recorded at Malin Head Meteorological Station, the following conclusions are made concerning the wind regime at the Culliagh Mountain site:

- The long-term mean wind speed is estimated to be 7.2 m/s at a height of 30 m above ground level.
- The standard error associated with the predicted long-term mean wind speed at 30 m is 0.26 m/s. If a normal distribution is assumed, the confidence limits for the prediction are as given in Table C.9.

Table C.9: Confidence limits – Wind speed

Probability of exceedence (%)	Long-term mean wind speed at 30 m (m/s)
90	6.9
75	7.0
50	7.2

Site wind flow and array loss calculations have been carried out, and from these we draw the following conclusions:

- The long-term mean wind speed averaged over all turbine locations at 45 m is estimated to be 8.1 m/s.
- The projected net energy capture of the proposed Culliagh Mountain Wind Farm is predicted to be 36.9 GWh/annum.

  These predictions of net energy include topographic effects, array losses, availability, electrical transmission losses, air density adjustments, and factors to account for turbine icing, high wind hysteresis and the wake effect of existing turbines.

  The net energy predictions presented above represent the long-term mean, 50 per cent exceedence levels, for the annual energy production of the wind farm. These values are the best estimate of the long-term mean value to be expected from the project. There is therefore a 50 per cent chance that, even when taken over very long periods, the mean energy production will be less than the value given in Table C.8. Estimates of long-term mean values with different levels of exceedence are set out in Table C.9.
- The standard error associated with the prediction of energy capture has been calculated and the confidence limits for the prediction are given in Table C.10.

Table C.10: Confidence limits – Energy

Probability of exceedence (%)	Net energy output (GWh/annum) 1-year average	Net energy output (GWh/annum) 10-year average
90	31.1	33.4
75	33.9	35.1
50	36.9	36.9
75	39.9	38.7
90	42.7	40.4

Actual Production of the Wind Farm

The Commissioning of the Culliagh wind farm took place in late 2000, and by November 2000 the wind farm was in full commercial operation. A review of the performance of the wind farm was undertaken in early 2002.

Table C.11 presents the expected long-term monthly energy production of the wind farm along with the actual energy production of the wind farm over the period from November 2000 to March 2002. It can be seen that individual months can deviate substantially from long-term expectations, for example February 2001 experienced production which was only 74 per cent of the long term expectations for this month, while in June 2001, 140 per cent of the long-term expectations for energy production in this month was produced. Over the 17 month period for which data are available, the actual production of the wind farm has been 1.6 per cent below long-term expectations. This figure is well within the 75 and 90 per cent exceedence levels for the prediction presented above. A detailed assessment of the availability of the wind farm over the above operational period has not been undertaken, but it is understood that high availability levels have been achieved.

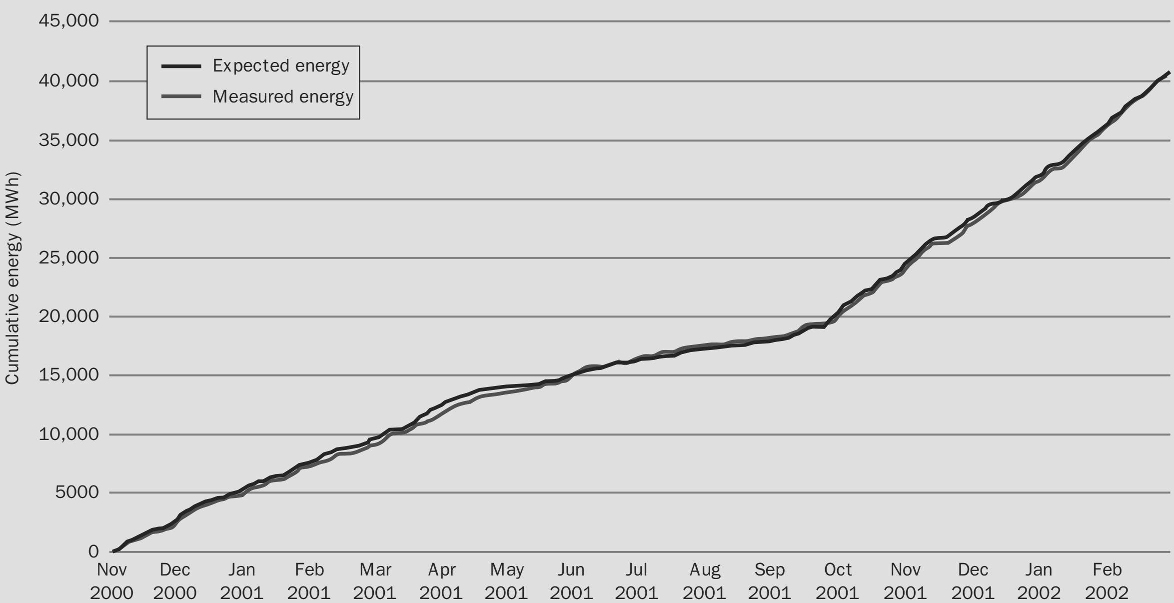
The data recorded at Malin Head indicate that the windiness of the period from November 2000 to March 2002 was some 4.9 per cent down on long-term expectations, making suitable assumptions about the seasonal variation of wind speed. This implies that over the longer term it is likely that the energy production of the wind farm will in fact exceed the central estimate value of 36.9 GWh/annum and may settle at a level which is close to the 25 per cent exceedence level presented in Table C.10. A more detailed assessment which includes issues such as wind direction, air density and availability would be required to provide a revised central estimate of wind farm production.

A separate validation of the accuracy of the modelling techniques employed to predict the long-term energy production of the Culliagh Mountain Wind Farm was undertaken. A comparison was made between the expected energy production of the wind farm, based on the actual mean wind speed recorded at Malin Head Meteorological Station, and the actual wind farm energy production. This was undertaken on an hourly basis. Thus the accuracy of the correlation relationships between Malin Head and the site and of the site flow model and turbine wake models was assessed using a 'wind in–energy out' test. Suitable adjustments were made to reflect the actual air density at the site. The comparison was undertaken for the operational period described above and data were only compared where all turbines were available and when wind farm SCADA data and data from Malin Head Meteorological Station were also available. Using these criteria, a comparison was made over a total of approximately

Table C.11: Expected and actual production of Culliagh Mountain Wind Farm

Month	Year	Expected production (GWh)	Actual production (GWh)
Nov	2000	3.670	3.703
Dec	2000	3.990	3.530
Jan	2001	4.270	3.546
Feb	2001	3.870	2.876
Mar	2001	3.840	3.410
Apr	2001	2.530	2.850
May	2001	2.160	1.699
Jun	2001	1.860	2.608
Jul	2001	2.050	1.813
Aug	2001	2.210	1.538
Sep	2001	2.850	2.941
Oct	2001	3.600	4.369
Nov	2001	3.670	3.645
Dec	2001	3.990	3.679
Jan	2002	4.270	4.801
Feb	2002	3.870	4.604
Mar	2002	3.840	4.037
	Total	56.540	55.649

Figure C.10: Cumulative plot showing measured energy against concurrent expected energy for the operating period



8300 hours. The results of the comparison of the expected and actual energy production of the wind farm are presented in Figure C.10 as a cumulative plot. Over the full period considered, the actual production was 99.7 per cent of the expected energy production of the wind farm, which provides confidence in the accuracy of the methods employed. It is noted that for individual months and for individual turbines larger discrepancies between the expected and actual energy production are observed.

Concluding Remarks

Appendix C has shown that the techniques outlined in the main text can be used to predict the behaviour of a wind farm with a good level of agreement. It has also demonstrated that the methods can be used to determine both mean values and associated uncertainties. It is hoped that it has proved a useful illustration of the techniques which are presently used by the industry.

APPENDIX D: DETAILED DESCRIPTION OF CORRELATION TECHNIQUES

Over the past decade, there has been an ongoing industry debate over different correlation methodologies which can be used for the prediction of the long-term mean wind speed at a site. All correlation methods have a common feature in that they:

1. establish a relationship between the concurrent data recorded at the site and reference station; and
2. apply the relationship to the historical data recorded at the reference station to predict the long-term wind regime at the site.

Such methodologies are commonly called measure correlate predict (MCP) analyses. Variables in such correlation analyses mooted over the past decade include those defined in Tables D.1 and D.2.

The tables present a bewildering array of options. While the technical merit of some methods over other methods can be argued, experience has shown that where the wind regimes at the site and reference meteorological station are well correlated, the results obtained tend to be relatively insensitive to the specific correlation methodology adopted. For cases where the correlation between the site and reference station is less good, then significant divergence is sometimes seen between the results obtained with different methods. In such circumstances, careful checks are required to ensure that the correlation is sufficiently good to justify the use of the reference meteorological station at all. Due consideration also needs to be given to the interpretation of the uncertainty associated with a specific correlation methodology.

The methods based on ten-minute data or hourly data typically use the long-term wind rose recorded at the reference meteorological station. Those based on daily or monthly correlations are dependent on the site wind rose. It is often pragmatically observed that where hourly or ten-minute correlations between a site and reference station are poor, a reasonable correlation is observed over longer time periods such as a month.

Table D.1: Prediction methodologies based on ten-minute or hourly data

Technique	Option 1	Option 2	Others
Directional bin size	30 degrees	Other	
Regression analysis technique	Principal component analysis	Least squares fit	
Fitting method	One parameter fit	Two parameter fit	Non-linear
Low wind speed cut-off	Exclude lowest wind speed data	Include lowest wind speed data	

Table D.2: Prediction methodologies based on longer-term data

Technique	Option 1	Option 2	Others
Averaging period	Monthly	Daily	
Fitting method	One parameter fit	Two parameter fit	Non-linear
Threshold for data coverage	Varies		

Detailed Description of a Measure Correlate Predict Analysis

A detailed description of the steps within a measure correlate predict analysis is described below based on hourly data from the site and reference station. As indicated in the previous section, different approaches may be used. In the following discussion the proposed wind farm site is referred to as the 'target site' and the meteorological station is referred to as the 'reference site'.

The first stage in the approach is to record, over a period of about one year, concurrent wind data from both the target site and the nearby reference site for which well-established long-term wind records are available. The short-term measured wind data are then used to establish the correlation between the winds at the two locations. Finally, the correlation is used to adjust the long-term historical data recorded at the reference site to calculate the long-term mean wind speed at the site.

The concurrent data are correlated by comparing wind speeds at the two locations for each of twelve 30 degree direction sectors, based on the wind direction recorded at the reference site. This correlation involves two steps:

1. Wind directions recorded at the two locations are compared to determine whether there are any local features influencing the directional results. Only those records with speeds in excess of, say, 5 m/s at both locations are used.
2. Wind speed ratios are determined for each of the direction sectors using a principal component analysis.

In order to minimise the influence of localised winds on the wind speed ratio, the data are screened to reject records where the speed recorded at the reference site falls below 3 m/s (or a slightly different level) at the target site. The average wind speed ratio is used to adjust the 3 m/s wind speed level for the reference site to obtain the different level for the target site, which ensures an unbiased exclusion of data. The wind speed at which this level is set is a balance between excluding low winds from the analysis and still having sufficient data for the analysis. The level used only excludes wind speeds below the cut-in wind speed of a wind turbine, which do not contribute to the energy production.

The result of the analysis described above is a table of wind speed ratios, each corresponding to one of 12 direction sectors. These ratios are used to factor the wind data measured at the reference site over the historical reference period to obtain the long-term mean wind speed at the target site. This estimate therefore includes the following influences:

- 'speed-up' between the target site and the reference site on a directional basis; this can be a very important characteristic, and sometimes speed-ups differ by a factor of as much as two; and
- the wind patterns at the reference site have been translated through the correlation process, so the long-term pattern at the target site has also been established.

APPENDIX E: SWT MANUFACTURERS AND THEIR MODELS

Less than 1 kW

The existing models and main features in this range are shown in Table E.1.

Table E.1: Existing wind turbine models, less than 1 kW

Wind turbine	Rated power (kW)	Rotor diameter (m)	Rotor type/no of blades	Generator type	Manufacturer/country
WG 503	0.025	0.51	HAWT (6)	PMG	Rutland (UK)
WG 910-3	0.090	0.91	HAWT (6)	PMG	Rutland (UK)
VT-60	0.12	0.9	HAWT (6)	PMG	Technoelektro (KRO)
VT-120	0.12	1.2	HAWT (5)	PMG	Technoelektro (KRO)
WS-0,15B/0,15C	0.12	0.30 (× 0.5)	VAWT	PMG	Windside (FIN)
WS-0,30 A	0.12	0.30 (× 1)	VAWT	PMG	Windside (FIN)
Pacific 100	01	0.928	HAWT (6)	PMG	Ampair (UK)
Flip 100	0.1	1.2	HAWT (3)	PMG	S&W Team (GER)
Inclin 250	0.25	1.35	HAWT (2)	PMG	Bornay (SP)
Twister 300 T	0.25	1.0 (× 1)	VAWT	PMG	Marc (GER)
Pacific 300	0.3	1.2	HAWT (3)	PMG	Ampair (UK)
Velter B	0.3	1.7	HAWT (3)	PMG	Solenersa (SP)
Speedy Vertical	0.3	1.2 (× 0.8)	VAWT (3)	PMG	Ropatec (IT)
FM 1803	0.34	1.8	HAWT (2)	PMG	Rutland (UK)
Superwind 350	0.35	1.12	HAWT (3)	PMG	Superwind (GER)
Air-X	0.4	1.14	HAWT (3)	PMG	Southwest (US)
StealthGen D-400	0.4	1.10	HAWT (5)	PMG	Eclectric (UK)
Aerocraft 502	0.5	2.4	HAWT (3)	PMG	Aerocraft (GER)
Enflo Windtec	0.5	0.71	HAWT (5)	PMG	Enflo Windtec (SWI)
Ampair Pacific	0.6	1.7	HAWT (3)	PMG	Ampair (UK)
Inclin 600	0.6	2.0	HAWT (2)	PMG	Bornay (SP)
Proven WT 600	0.6	2.55	HAWT (3)	PMG	Proven (UK)
Velter D	0.7	2.2	HAWT (3)	PMG	Solenersa (SP)
Aerocraft 752	0.75	2.4	HAWT (3)	PMG	Aerocraft (GER)
Espada	0.8	2.2	HAWT (2)	PMG	Fortis (NED)
Aerocraft 1002 H	1.0	2.4	HAWT (3)	PMG	Aerocraft (GER)
BWC Excell XL1	1.0	2.5	HAWT (3)	PMG	Bergey (US)
Lakota	1.0	2.1	HAWT (3)	PMG	Aeromax (US)
Whisper 100/200	0.9/1.0	2.1/3	HAWT (3)	PMG	Southwest (US)
Airdolphin Z-1000	1.0	1.8	HAWT (3)	PMG	Zephyr (JAP)
WS-1000	1.0	1.75	HAWT (3)	PMG	Windsave (UK)
Twister 300 T	1.0	1.9 (× 1.9)	VAWT (3)	PMG	Marc (GER)
WS-2AK/WS-2B	1.0	1.0 (× 2)	VAWT	PMG	Windside (FIN)
Easy Vertical	1.0	1.8 (× 1.15)	VAWT (3)	PMG	Ropatec (IT)

1 kW < SWT < 7 kW

The existing models and main features in this range are shown in Table E.2.

Table E.2: Existing wind turbine models, 1–7 kW

Wind turbine	Rated power (kW)	Rotor diameter (m)	Rotor type/no of blades	Generator type	Manufacturer/country
WS-4A/4AK/4C	1.2	1.0 (× 4)	VAWT	PMG	Windside (FIN)
Passaat	1.4	3.12	HAWT (3)	PMG	Fortis (NED)
Butterfly I	1.5	3.0	HAWT (3)	PMG	Energotech (GER)
SG 280	1.5	2.88	HAWT (3)	PMG	Geiger (GER)
Inclin 1500	1.5	2.86	HAWT (2)	PMG	Bornay (SP)
Velter I	1.5	3.1	HAWT (3)	PMG	Solenersa (SP)
Butterfly 1K	1.5	3.0	HAWT (3)	PMG	Energotech (GER)
Skystream 3,7	1.8	3.72	HAWT (3)	PMG	Southwest (US)
Antaris 2,5 KS	2.5	3/3.5	HAWT (3)	PMG	Heyde Windtechniks (GER)
Pawicon-2500	2.5	3.5	HAWT (3)	PMG	Pawicon (GER)
WT 2500	2.5	3.5	HAWT (3)	PMG	Proven (UK)
Tulipo	2.5	5.0	HAWT (3)	Asynchro + convert	WES (NED)
ARE 110	2.5	3.6	HAWT (3)	PMG	Abundant RE (US)
Turby 2,5	2.5	2 (× 2.65)	VAWT (3)	PMG	Turby (NED)
Inclin 3000	3.0	4.0	HAWT (2)	PMG	Bornay (SP)
Westwind 3	3.0	3.7	HAWT (3)	PMG	GP & GF Hill (AUS)
Simply Vertical	3.0	3.0	VAWT (3)	PMG	Ropatec (IT)
Whisper H175	3.2	4.5	HAWT (2)	PMG	Southwest (US)
Butterfly 3K	3.5	4.3	HAWT (3)	PMG	Energotech (GER)
Vento 5	5.0	5.0	HAWT (3)	PMG	Windeco (US)
ATS-1	5.0	5.4	HAWT (3)	PMG	Iskra (UK)
Aerosmart 5	5.0	5.1	HAWT (3)	Asynchro + gear	SMA (GER)
Montana	5.0	5.0	HAWT (3)	PMG	Fortis (NED)
Westwind 5	5.5	5.10	HAWT (3)	PMG	GP & GF Hill (AUS)
SWT 6000 AC	6.0	6.0	HAWT (4)	Asynchro + gear	Conergy (GER)
Inclin 6000	6.0	4.0	HAWT (3)	PMG	Bornay (SP)
WT 6000	6.0	5.5	HAWT (3)	PMG	Proven (UK)
Siroco	6.0	5.6	HAWT (2)	PMG	Eoltec (FRA)
QR 5	6.0	3.1 (× 5)	VAWT	PMG	QR (UK)
Maxi Vertical	6.0	4.7 (× 2.5)	VAWT (3)	PMG	Ropatec (IT)
AV-7	6.5	12.8	HAWT (3)	PMG	Aventa (GER)
Butterfly 6K	7.0	4.6	HAWT (3)	PMG	Energotech (GER)

7 kW < SWT < 50 kW

The existing models and main features in this range are shown in Table E.3.

Table E.3: Existing wind turbine models, 7–50 kW

Wind turbine	Rated power (kW)	Rotor diameter (m)	Rotor type/no of blades	Generator type	Manufacturer/country
SWT-7500	7.5	6.0	HAWT (4)	Asynchro + gear	Conergy (GER)
BWC EXCEL-R	7.5/10	6.7	HAWT (3)	PMG	Bergey (US)
WT 8000	8.0	5.4	HAWT (3)	PMG + gear	Webs (GER)
Aeroturbine	9.0	8.0	HAWT (3)	Synchron + gear	Aeroturbine (GER)
Aircon 10 S	9.8	7.1	HAWT (3)	PMG	Aircon (GER)
Alize	10.0	7.0	HAWT (3)	PMG	Fortis (NED)
Enwia E0	10.0	9.0	HAWT (3)	Synchron + gear	Alex Giersh (POL)
ARE 442	10.0	7.2	HAWT (3)	PMG	Abundant RE (US)
Westwind 10	10.0	6.20	HAWT (3)	PMG	GP & GF Hill (AUS)
Gaia Wind	11.0	13.0	HAWT (2)	Asynchro + gear	Gaia (DK)
WT 15000	15.0	9.0	HAWT (3)	PMG	Proven (UK)
Velter XV	15.0	7.2	HAWT (3)	PMG	Solenersa (SP)
GEV 10/20	15/20	10	HAWT (2)	Asynchro + gear	Vergnet (FRA)
Westwind 20	20.0	10.4	HAWT (3)	PMG	GP & GF Hill (AUS)
Gazelle 20	20.0	11.0	HAWT (3)	Asynchro + gear	Gazelle (UK)
Jacobs 20	20.0	9.5	HAWT (3)	PMG	Jacobs (US)
JIMP 20	20.0	8–10	HAWT (3)	PMG	Jonica Impiati (IT)
Big Star Vertical	20.0	8.5 (× 4.3)	VAWT (5)	PMG	Ropatec (IT)
WS-12	25.0	2.0 (× 6)	VAWT	PMG	Windside (FIN)
Wind Runner	25.0	11.0	HAWT (3)	PMG	Eoltec (FRA)
P14-30	30.0	14.0	HAWT (2)	PMG	Pitchwind (SWE)
Enwia E40	30.0	10.0	HAWT (3)	Synchron + gear	A Giersch (POL)
FL30	30.0	13.0	HAWT (3)	Asynchro + gear	Furlaender (GER)
Subaru 15/40	40.0	15.0	HAWT (3)	PMG	Subaru (JAP)
WT 50	50.0	11.5	HAWT (3)	PMG + gear	Webs (GER)
Vertikon H 50	50.0	12.0 (× 12.5)	VAWT (3)	PMG	MARC (GER)
EW15	50.0	15	HAWT (3)	Asynchro + gear	Entegrity Wind (US)

SWT greater than 50 kW

The existing models and main features in this range are shown in Table E.4.

Table E.4: Existing wind turbine models, 50–100 kW

Wind turbine	Rated power (kW)	Rotor diameter (m)	Rotor type/ no of blades	Generator type	Manufacturer/country
WT 50 SC	55.0	13.5	HAWT (3)	Asynchro + gear	Windtower (CZECH)
WES 18	80.0	18.0	HAWT (2)	Asynchro + convert	WES (NED)
E-20	100.0	20.0	HAWT (3)	Synchronous multipole	Enercon (GER)
V20	100.0	20.0	HAWT (2)	Asynchro + gear	Ventis (GER)
FL 100	100.0	21.0	HAWT (3)	Asynchro + gear	Furlaender (GER)
Enertech 100	100.0	*	HAWT (3)	*	Enertech (GER)
Subaru 22/100	100.0	22.0	HAWT (3)	PMG	Fuji Heavy Industries (JAP)
Northwind 100	100.0	19/20/21	HAWT (3)	PMG	DES (US)

* Data not yet available

APPENDIX F: CURRENT NATIONAL AND EUROPEAN R&D

The Main EU-Funded Projects

In 2006 more than 20 R&D projects were running with the support of FP6 and FP7 (the Framework Programmes are the main EU-wide tool for supporting strategic research areas).

The management and monitoring of projects is divided between two European Commission Directorate-Generals: the Directorate-General for Research (DG Research), for projects with medium- to long-term impact, and the Directorate-General for Transport and Energy (DG TREN), for demonstration projects with short- to medium-term impact on the market.

Private Initiatives

EOLIA (SPAIN)

The government-funded programme CENIT (the National Strategic Consortia for Technological Research) is focused on research activities. The target of the CENIT funding programme is to support large public–private consortiums and is aimed at overcoming strategic issues. In this framework, the private initiative EOLIA was launched in 2007.

The purpose of EOLIA is to carry out the research needed for the new technologies for offshore wind in deep waters. This covers a broad range of topics, from support structures, cables and moorings to project development (environmental impact assessment, wind resource and planning). It includes future applications and synergies (desalination and aquiculture).

The project's total budget of €34 million is being supported with €17 million from the Centre for the Development of Industrial Technology (CDTI). It started in 2007 and will be completed in 2010.

Several companies from the Acciona Group are participating in EOLIA (energy, wind turbines, desalination, infrastructure, engineering), together with major partners such as ABB, Construcciones Navales del Norte Shipyard, General Cable, Ingeteam Group, Ormazabal and Vicinay, smaller partners such as Tinamenor and IMATIA, and the participation of research centres such as the National Renewable Energy Centre (CENER).

International Networks

THE EUROPEAN ACADEMY OF WIND ENERGY (EAWE)

The EAWE is a cooperation initiative on wind energy R&D made up of research institutes and universities in seven countries: Germany, Denmark, Greece, The Netherlands, Spain, the UK and Norway. The Academy was founded to formulate and execute shared R&D projects and to coordinate high-quality scientific research and education on wind energy at a European level. The core group is made up of 25 bodies, representing seven EU countries and more than 80 per cent of long-term research activity in the field of wind energy.

The activities of the EAWE are split into:

- integration activities such as PhD exchanges, exchange of scientists and the exploitation of existing research infrastructures;
- activities for the spreading of excellence, through the development of international training courses, dissemination of knowledge, support to SMEs and standardisation; and
- long-term research activities (see below).

Table F.1 lists thematic areas and topics that have been identified as first priority long-term R&D issues for EAWE's joint programme of activities.

THE EUROPEAN RENEWABLE ENERGY CENTRES AGENCY

The European Renewable Energy Centres Agency (EUREC) was established as a European economic interest grouping in 1991 to strengthen and rationalise

Table F.1: Priority long-term R&D issues for EAWE's joint programme of activities

Long-term wind forecasting	• Wind resources • Micro-siting in complex terrain • Annual energy yield • Design wind conditions (turbulence, shear, gusts, extreme winds) offshore, onshore and in complex terrain
Wind turbine external conditions	• Characteristics of wind regime and waves • Atmospheric flow and turbulence • Interaction of boundary layer and large wind farms • Prediction of exceptional events
Wind turbine technology	• Aerodynamics, aeroelasticity and aeroacoustics • Electrical generators, power electronics and control • Loads, safety and reliability • Materials, structural design and composite structures • Fracture mechanisms • Material characterisation and life-cycle analysis • New wind turbine concepts
Systems integration	• Grid connection and power quality issues • Short-term power prediction • Wind farm and cluster management and control • Condition monitoring and maintenance on demand • New storage, transmission and power compensation systems
Integration into the energy economy	• Integration of wind power into power plant scheduling and electricity trading • Profile-based power output and virtual power plants • Transnational and transcontinental supply structures • Control of distributed energy systems

the European research, demonstration and development efforts in all renewable energy technologies. As an independent, member-based association, it incorporates 48 prominent research groups from all over Europe.

EUREC members' research fields include solar buildings, wind, photovoltaics, biomass, small hydro, solar thermal power stations, ocean energy, solar chemistry and solar materials, hybrid systems, developing countries, and the integration of renewable energy into the energy infrastructure.

THE EUROPEAN WIND ENERGY TECHNOLOGY PLATFORM (TPWind)

TPWind's task is to identify and prioritise areas for increased innovation and new and existing R&D tasks. Its primary objective is to make overall reductions in the social, environmental and technological costs of wind energy. This is reflected in TPWind's structure, where the issues raised by the working groups (see below) are focused on areas where technological improvement leads to significant cost reductions.

This helps to achieve the EU's renewable electricity production targets. The Platform develops coherent recommendations, with specific tasks, approaches, participants and the necessary infrastructure. These are given in the context of private R&D and EU and Member State programmes, such as the EU's FP7.

TPWind is a network of more than 150 members, representing the whole industry from all over the EU. It is split into seven technical working groups, covering the issues of:

1. wind conditions;
2. wind power systems;
3. wind energy integration;
4. offshore deployment and operations;
5. market and economics;
6. policy and environment; and
7. R&D financing.

It comprises a Mirror Group, which includes representatives of the Member States, and a Steering Committee representing the whole industry. Detailed information is available at www.windplatform.eu.

GEO – THE WIND ENERGY COMMUNITY OF PRACTICE

The Wind Energy Working Group is part of the Energy Community of Practice, which is a section of the Group on Earth Observation (GEO). Under the auspices of the G8, GEO is an international initiative, aiming to establish the Global Earth Observation System of Systems (GEOSS) within the next ten years.

The Wind Energy Working Group directly contributes to the goals of one of the nine societal benefit areas of GEOSS, the energy area, for the improved management of energy resources. Specifically:

> *GEOSS outcomes in the energy area will support environmentally responsible and equitable energy management; better matching of supply and demand of energy; reduction of risks to energy infrastructure; more accurate inventories of greenhouse gases and pollutants; and a better understanding of renewable energy potential.* (GEOSS 10-Year Implementation Plan, Section 4.1.3)

THE INTERNATIONAL ELECTROTECHNICAL COMMISSION (IEC)

The IEC, through its Technical Committee 88, is responsible for the development of standards relevant to wind turbine generator systems. It has produced standards for design requirements, power curve measurement, power quality control, rotor blade testing, lightning protection, acoustic noise measurement techniques, measurement of mechanical loads, and communications for monitoring and control of wind power plants.

Its current work programme includes both standards and design requirements for offshore wind turbines, for gearboxes and for wind farm power performance testing.

THE INTERNATIONAL MEASURING NETWORK OF WIND ENERGY INSTITUTES (MEASNET)

MEASNET is a cooperation of institutes that are engaged in the field of wind energy and want to ensure high-quality measurements and the uniform interpretation of standards and recommendations and obtain interchangeable results. The members have established an organisational structure for MEASNET, and they periodically perform mutual quality assessments of their harmonised measurements and evaluations.

This network was founded in 1997. It now has ten full members and five associate members.

THE EUROPEAN COMMITTEE FOR ELECTROTECHNICAL STANDARDIZATION (CENELEC)

CENELEC was created in 1973 as a result of the merging of two previous European organisations: CENELCOM and CENEL. Nowadays, CENELEC is composed of the National Electrotechnical Committees of 30 European countries. In addition, eight National Committees from neighbouring countries participate in CENELEC's work with affiliate status.

CENELEC's mission is to prepare voluntary electrotechnical standards that will help develop the Single European Market/European Economic Area for electrical and electronic goods and services, removing barriers to trade, creating new markets and cutting compliance costs.

THE INTERNATIONAL ENERGY AGENCY (IEA)

In its report 'Long-term research and development needs for wind energy for the time frame 2000 to 2020' (IEA, 2001), the Executive Committee of the IEA's Implementing Agreement for Wind Energy stated that continued R&D is essential for providing the reductions in cost and uncertainty that are necessary for reaching the anticipated deployment levels of wind energy.

In the mid-term, the report suggests the following R&D areas of major importance for the future deployment of wind energy: forecasting techniques, grid integration, public attitudes and visual impact.

In the long term, the Implementing Agreement sees R&D focusing on closer interaction of wind turbines and their infrastructure as a priority.

Since its inception, the Executive Committee of the Implementing Agreement has been involved in a wide range of R&D activities. The current research and development activities are organised into seven tasks (referred to as 'annexes'), giving an insight into its perception of current R&D priorities:

- **Annex XI: Base technology information exchange**. This refers to coordinated activities and information exchange in two areas: i) the development of recommended practices for wind turbine testing and evaluation, including noise emissions and cup anemometry, and ii) joint actions in specific research areas such as turbine aerodynamics, turbine fatigue, wind characteristics, offshore wind systems and forecasting techniques.
- **Annex XIX: Wind energy in cold climates**. The objectives here include i) gathering and sharing information on wind turbines operating in cold climates, ii) establishing a formula for site classification, aligning meteorological conditions with local needs, and iii) monitoring the reliability and availability of standard and adapted turbine technology, as well as the development of guidelines.
- **Annex XX: HAWT aerodynamics and models from wind tunnel tests and measurements**. The main objective is to gather high-quality data on aerodynamic and structural loads for HAWTs, to model their causes and to predict their occurrence in full-scale machines.
- **Annex XXI: Building dynamic models of wind farms for power system studies that aim to assist in the planning and design of wind farms**. These studies develop models for use in combination with software packages for the simulation and analysis of power system stability.
- **Annex XXIII: Offshore wind energy technology development**. The aim is to identify and conduct R&D activities towards the reduction of costs and uncertainties and to identify and organise joint research tasks between interested countries.
- **Annex XXIV: Integration of wind and hydropower systems into the electricity grid**. The goal is to identify feasible wind/hydro system configurations, limitations and opportunities, involving an analysis of the integration of wind energy into grids fed by a significant proportion of hydropower, and opportunities for pumped hydro storage.
- **Annex XXV**: The 'design and operation of power systems with large amounts of wind power production' has recently been added as an additional task.

THE OFFSHORE WIND ENERGY NETWORK (OWE)

OWE is an independent source of information for professionals working in the field of offshore wind energy. It is also a gateway to several research projects on offshore wind energy. It provides a survey of the existing offshore wind farms, and information on existing offshore-related research projects and networks (for example CA-OWEE, COD and WE@SEA).

National Networks

DENMARK

Megavind

The Megavind partnership is the result of a government initiative for the development of environmentally effective wind technology. It addresses the challenges Denmark is facing in order to maintain its position as an internationally leading centre of competence within the field of wind power.

The partnership is the catalyst and initiator of a strengthened testing, demonstration and research strategy within the field of wind power in Denmark. It aims to think innovatively in regard to validation, testing and demonstration within wind power technology and the integration of wind power into the entire energy system. It therefore recommends creating an accumulated strategy for testing and demonstrating:

- components and turbine parts;
- wind turbines and wind farms; and
- wind power plants in the energy system.

Long-term university research and education in general should make a priority of the fundamental or generic technologies that are part of the development of wind turbines and wind power plants. These include:

- turbine design and construction;
- blades – aerodynamics, structural design and materials;
- wind loads and siting;
- the integration of wind power into the energy system; and
- offshore technology.

Megavind's recommendations will function as a reference for strategic research within wind power in the coming years, thus becoming the valid research strategy for wind power in Denmark.

GERMANY

The Centre of Excellence for Wind Energy (CE Wind)

The research network CE Wind, founded in 2005, includes the universities of Schleswig-Holstein. Through scientific research, CE Wind deals with fundamental questions relating to the wind turbines of the future, wind parks and the corresponding infrastructure.

CE Wind looks at the main issues regarding grid connection and integration, the design of rotor blades, generators, towers and foundations, operation monitoring and maintenance, impact on the environment of turbines in the multi-megawatt class, and operation in extreme local conditions.

ForWind

ForWind was founded in August 2003. It combines the interdisciplinary competencies of the universities of Oldenburg and Hanover and of its associated members, the universities of Stuttgart and Essen, in the field of wind power utilisation.

ForWind bridges basic research at the universities with demands from the industry for applied innovative wind energy conversion techniques. The research per-formed ranges from estimation of the wind resource to the grid integration of wind power. The research priorities are:

- wind resources and offshore meteorology;
- aerodynamics of rotor blades;
- turbulence and gusts;
- wave and wake loads;

- analysis of Scour Automatic System and load identification;
- material fatigue and lifetime analysis;
- material models for composite rotor blades;
- structural health monitoring for blades, tower and the converting system;
- hydro-noise reduction;
- interaction of ground and foundation structure;
- grouted joints for offshore constructions;
- electrical generator power system simulation and analysis of power quality; and
- grid connection of large-scale wind farms.

Research at Alpha Ventus (RAVE)

To help launch the deployment of offshore wind in German waters, the German Federal Ministry for the Environment (BMU) will support the offshore test wind farm Alpha Ventus in the North Sea with a research budget of about €50 million over the next few years.

This research initiative was named RAVE – Research at Alpha Ventus – and consists of a variety of projects connected with the installation and operation of Alpha Ventus. The different project consortia in RAVE are made up of most of the offshore research groups in Germany. RAVE is represented and coordinated by the ISET institute in Kassel.

In order to provide all participating research projects with detailed data, the test site will be equipped with extensive measurement instrumentation. The overall objective of the research initiative is to reduce the costs of offshore wind energy deployment in deep water. The institutes and companies participating in the RAVE initiative have prepared projects on the following topics so far:

- Obtaining joint measurements and data management;
- Analysis of loads and modelling, and further development of the different components of offshore wind turbines;
- loads at offshore foundations and structures;
- monitoring of the offshore wind energy deployment in Germany – 'Offshore WMEP';
- grid integration of offshore wind energy;
- further development of Lidar wind measuring techniques, analysis of external conditions and wakes;
- measurement of the operating noises and modelling of the sound propagation between tower and water; and
- environmental research.

SPAIN

The Spanish Wind Energy Technology Platform (REOLTEC)

REOLTEC (Techno-Scientific Wind Energy Network) was created in July 2005 with the aim of integrating and coordinating actions focused on research, development and innovation activities in the field of wind energy in Spain. In the last two years, the network has created working groups focused on different topics related to wind energy: wind turbines, applications, resource and siting, offshore, grid integration, certification, and social impact.

REOLTEC has the full support of AEE (the Spanish Wind Energy association). It is made up of the main players in the wind energy companies, research centres, universities and government agencies in Spain. This gives the network a wide-ranging point of view on the best path to follow in the coming years.

THE NETHERLANDS

INNWIND

The long-term R&D programme of the INNWIND consortium is funded by the government of The

Netherlands. The budget is €1.5 million per year. The consortium partners are:

- the Energy Research Centre of The Netherlands;
- Delft University of Technology; and
- the Knowledge Centre WMC (Wind Turbine Materials and Constructions).

The aim of the programme is to develop expertise, concepts, computer models and material databases that will be made available and applicable through a new generation of software tools. This is to enable the construction of large, robust, reliable, low-maintenance and cost-effective offshore wind turbines that are readily available for developers.

The INNWIND R&D priority areas are:

- concepts and components;
- aeroelasticity;
- materials and constructions;
- model development and realisation of an integrated modular design tool; and
- design guidelines.

We@Sea

We@Sea is a body funded by the Government of The Netherlands. It focuses on the national target of 6 GW offshore for 2020. The total budget is €26 million for five years. The We@Sea research priorities are:

- integration of wind power, and scenarios for its development;
- offshore wind power generation;
- spatial planning and environment;
- energy transportation and distribution;
- the energy market and financing;
- installation, exploitation, maintenance and dismantling; and
- training, education and dissemination of knowledge.

THE UK

Collaborative Offshore Wind Farm Research into the Environment (COWRIE)

COWRIE is an independent company set up to raise awareness and understanding of the potential environmental impacts of the UK's offshore wind farm programme. Identified research areas are:

- birds and benthos;
- electromagnetic fields;
- marine bird survey methodology;
- remote techniques; and
- underwater noise and vibration.

The Offshore Wind Energy Network (OWEN)

OWEN is a joint collaboration between industry and researchers. It promotes research on all issues connected with the development of the UK offshore wind energy resource (for example shallow water foundation design, submarine cabling, power systems, product reliability and impacts on the coastal zone).

The main aims of OWEN are:

- to identify, in detail, the research required by the UK wind energy industry so that the offshore wind energy resource can be developed quickly, effectively and efficiently;
- to provide a forum where specific research or development issues can be discussed;
- to ensure that regular reports of ongoing research projects are disseminated to relevant academic and industrial partners; and
- to ensure that the final results of any research project are widely publicised through tools such as conferences, newsletters and journals, whilst remaining aware of the need to preserve commercial confidentiality in the relevant cases.

The UK Energy Research Centre (UKERC)

The UK Energy Research Centre's mission is to be the UK's pre-eminent centre of research and source of authoritative information and leadership on sustainable energy systems.

UKERC undertakes world-class research addressing whole-system aspects of energy supply and use, while developing and maintaining ways of enabling cohesive research on energy. Research themes include:

- demand reduction;
- future sources of energy;
- energy infrastructure and supply;
- energy systems and modelling;
- environmental sustainability; and
- materials for advanced energy systems.

ITI Energy

ITI Energy is a private company, part of ITI Scotland Ltd. Its aims are the funding and managing of early stage technology development. It benefits from a long-term direct funding commitment from the Scottish Government through Scottish Enterprise. The available budget is £150 million over ten years. The ITI Energy programme includes:

- battery management systems;
- composite pipeline structure;
- hydrogen handling materials;
- interior surface coating;
- large-scale power storage;
- rechargeable batteries;
- wind turbine access systems;
- active power networks; and
- offshore renewables programmes.

The Energy Technologies Institute (ETI)

The ETI is an energy, research and development institute that is planned to begin operating in the UK in 2008. It is being set up by the UK government to 'accelerate the development of secure, reliable and cost-effective low-carbon energy technologies towards commercial deployment'. This new institute is supported by a number of companies as a 50:50 public–private partnership. The institute is expected to work with a range of academic and commercial bodies.

Conclusion

This large number of networks shows the willingness of the research sector to coordinate its efforts. It demonstrates the need for research, and the quest for improved efficiency through knowledge-sharing.

Building a research network is a way to strengthen the whole wind energy community, and to improve its attractiveness for the private sector, which can take advantage of a high level of expertise and information.

The European Wind Energy Technology Platform is the instrument that brings together institutes, research networks and private companies in order to set the research and market development priorities for the wind energy sector up to 2030.

Special Focus: Design Software for Wind Turbines

Currently used design tools are only partially suitable for the reliable design of very large wind turbines, and have only been validated and verified by means of measurements on what are now 'medium size' machines. Some physical properties that are irrelevant in small and medium-sized turbines cannot be neglected in the design of large, multi-megawatt turbines.

It is difficult to define for these machines a clear upper limit to which existing design tools can be applied. However, it is generally acknowledged by experts that the design risks increase considerably for machines with rotors of over around 125 m in diameter.

For this reason, new design tools are needed, supplemented with new features that take into account such issues as extreme blade deflections and wave loading of support structures in the case of offshore turbines. Such new tools will be essential if a new generation of wind turbines is to be designed and manufactured in a cost-effective way.

Moreover, in the case of offshore and complex or forested terrains, large uncertainties remain on the evaluation of local wind resources and loads. At this stage, advanced flow modelling for wind loads and resources has still not been verified and validated at a satisfactory level. These uncertainties on loadings should be taken into account in the design process.

High-quality design tools reduce the need for elaborating and performing expensive testing of prototypes, reduce the time required to market innovative concepts, and provide manufacturers with a competitive advantage. The probability of failure of wind turbines newly introduced to the market will also reduce, providing financiers and end users with a lower risk profile, less uncertainty and consequently lower electricity costs to the consumer.

One of the key challenges in developing design tools suitable for very large wind turbines is to understand and model aeroelastic phenomena. Figure F.1 gives an impression of the many dynamic external forces that act on wind turbines and the many ways the wind turbine structure may be distorted and may vibrate.

On the left, all the external dynamic forces that expose a turbine to extreme fatigue loading are indicated. On the right the various vibration and deflection modes of a wind turbine can be seen.

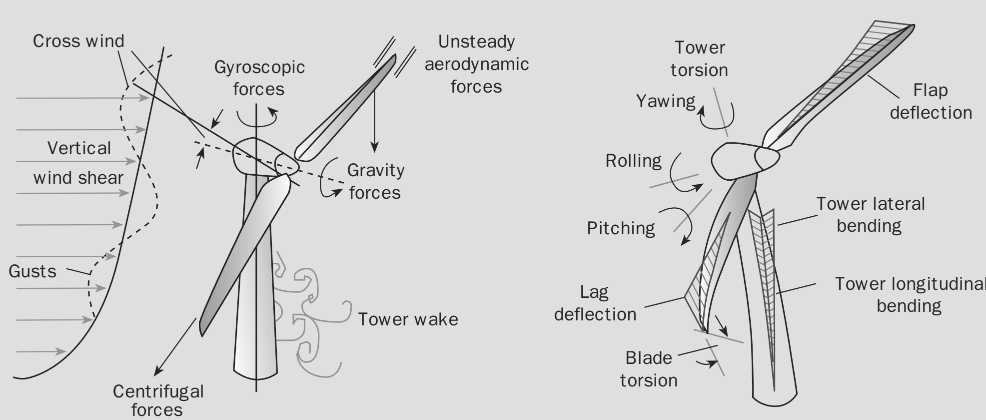
From the dynamic point of view, a wind turbine is a complex structure to design reliably for a given service lifetime.

In fact, the fatigue loading of a wind turbine is more severe than that experienced by helicopters, aircraft wings and car engines. The reason is not only the magnitude of the forces but also the number of load cycles that the structure has to withstand during its lifetime of 20 or more years (see Figure F.2).

The larger the wind turbine becomes, the more extreme the fatigue loading becomes. Thus, system identification and inverse methods for providing the loads under real conditions are required.

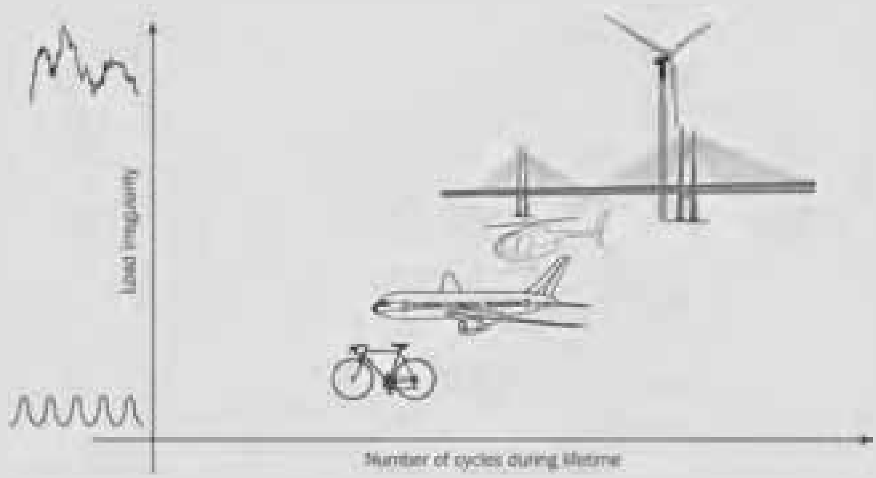
Computational fluid dynamics (CFD) tools are currently being developed into the design codes of the future. Large-scale wind turbines can be equipped with

Figure F.1: Modelling of the complete aeroelastic system of a wind turbine using symbolic programming



Source: Kießling F, Modellierung des aeroelastischen Gesamtsystems einer Windturbine mit Hilfe symbolischer Programmierung. DFVLR-Report, DFVLR-FB 84-10, 1984.

Figure F.2: The fatigue loading of a wind turbine during its lifetime is large compared to, for example, bridges, helicopters, aeroplanes and bicycles



Source: WMC (TU Delft-ECN)

sensors that record dynamic behaviour. Once developed, experimental verification for virtually all new design tools needs to be carried out, taking into account external flow conditions.

Figure F.3 illustrates the complexity of rotor flow. A number of numerical codes exist to analyse and design components and subsystems such as drive trains, rotor blades, drive train dynamics and tower dynamics.

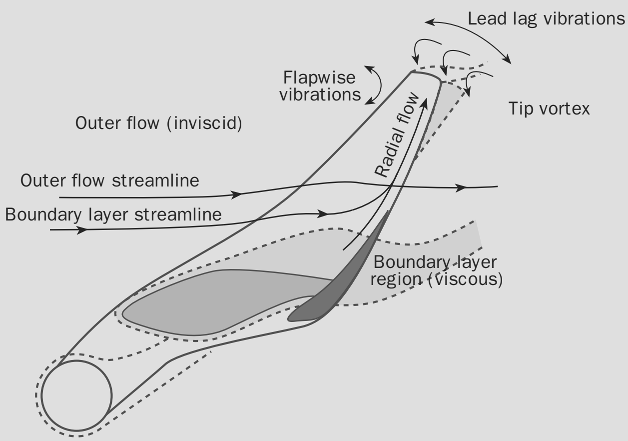
Currently, different design packages are not fully compatible with each other. It is therefore not possible to consider the system as a whole in the design phase. In terms of system optimisation, this implies that partial optimisation is performed on subsystems. This local optimisation is unlikely to be equivalent to the result of a global approach to optimisation.

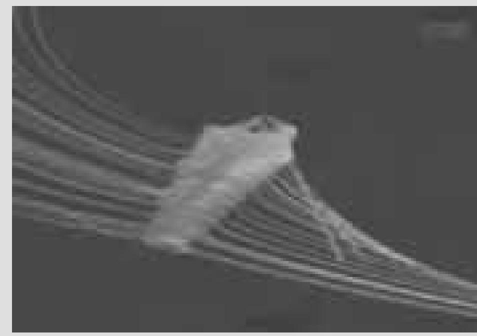
Integral design methods include sub-design routines such as those for blades, power electronic systems, mechanical transmission, support structures and transport, and installation loads. These methods should be thoroughly verified during their development and introduced into the standard design and certification processes. Through its dedicated work package, 'Integral design approaches and standards', the current UpWind project will bring solutions to this specific issue.

Many of the elements necessary for an integral design base are available. However, existing knowledge is not fully applied. Future research should therefore focus not only on improving the methodology, but also on improving wind turbine manufacturers', component manufacturers' and certification bodies' access to the know-how.

The interaction between flow and blade deformation is very complex. Three-dimensional aspects (tip vortices), axial flow, flow detachment (stall) and flow-induced vibrations all have to be taken into account in

Figure F.3: Sketch of three-dimensional flow, stall-induced vibrations and centrifugal effects on flow





Source: Van Garrel, ECN; Risø DTU/TUDk

order to guarantee stable operation of the blade and accurate calculation of its lifetime. CFD is likely to be used in the future for detailed flow calculations as the computing time is reduced and the non-linear effects are better understood and modelled. The picture on the right in Figure F.3 shows the result of a CFD calculation of the flow around a rotor blade. The future vision is that integral design of a wind turbine will be able to be carried out so reliably that no extensive field tests will be needed before market introduction.

APPENDIX G: TRANSMISSION SYSTEMS IN EUROPE

Power system operators have been cooperating for decades, mainly to maximise system reliability and quality of power supply, while optimising the use of primary energy and capacity resources. As a result, five regional zones have emerged in Europe:

1. the synchronous zone of the Nordic countries;
2. the synchronous zone of the UCTE countries;
3. the synchronous zone of Great Britain;
4. the synchronous zone of the island of Ireland (Republic of Ireland and Northern Ireland); and
5. the Baltic Interconnected Power System.

The Synchronous Zone of the Nordic Countries

This synchronous zone comprises the power systems of Finland, Sweden, Norway and Eastern Denmark. The capacity of these power plants is around 90 GW and the annual electricity production is nearly 400 TWh, serving around 25 million people. The total primary control reserve is 1600 MW (operating reserve 600 MW and disturbance reserve 1000 MW). The transmission system operators (TSOs) of these countries have organised a cooperative body, NORDEL, whose primary objective is to create the conditions for, and to develop further, an efficient and harmonised Nordic electricity market.

This synchronous zone is interconnected by DC lines to Poland, Germany and Russia.

The Synchronous Zone of the UCTE Countries

The Union for the Coordination of Transmission of Electricity (UCTE) is the association of transmission system operators in continental Europe for 23 countries. The UCTE network ensures electricity supply for some 500 million people in one of the biggest electrical synchronous interconnections in the world. The estimated plant capacity is 603 GW (end 2004) and the total primary control reserve is 3 GW.

This synchronous area is interconnected both internally and across borders.

The Synchronous Zone of Great Britain

The National Grid Company (NGC) is now the system operator of the electricity transmission system on the islands of Great Britain, including England, Wales and Scotland. In April 2005, the Scottish system came under NGC control, although ownership is still separate.

Distribution is handled by several separate companies and the capacity of power plants is about 81 GW. The system is interconnected by DC lines with France (2000 MW) and Northern Ireland (450 MW) and is able to sustain a loss of 1320 MW.

The Synchronous Zone of (the Island of) Ireland

This smallest synchronous zone is operated by two TSOs: ESB and SONI. Their power system has a total installed capacity of power plants of about 7.6 GW and is connected to the Great Britain synchronous zone by a DC cable of 450 MW. The system reserve is 400 MW.

The Baltic Interconnected Power System

The interconnected grid of the Baltic States, Lithuania, Latvia and Estonia, is not synchronously linked to the power grids of other EU countries. There is a link with Finland, however, and links are also planned with Poland and Sweden. In 2006, the TSOs of these three countries established a cooperative organisation, BALTSO.

APPENDIX H: BASICS CONCERNING THE OPERATION AND BALANCING OF POWER SYSTEMS

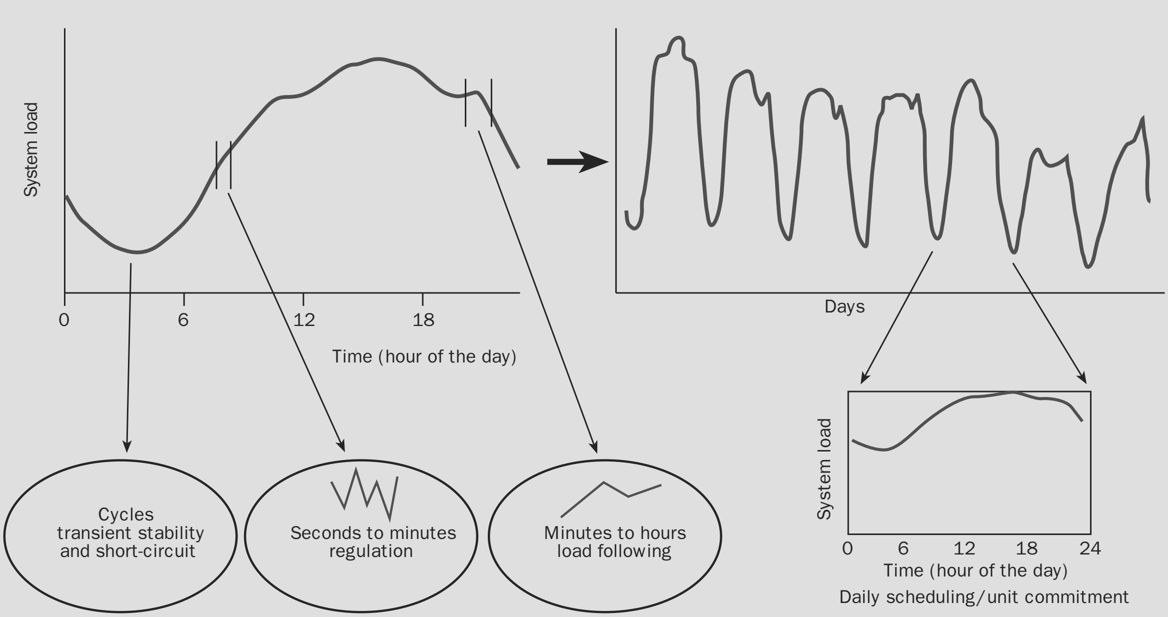
In power systems, the balance between generation and consumption must be maintained continuously. The essential parameter in controlling the energy balance in the system is system frequency. If generation exceeds consumption, the frequency rises and if consumption exceeds generation, the frequency falls. As shown in Figure H.1, power system operation covers several timescales, ranging from seconds to days. Ultimately, it is the responsibility of the system operator to ensure that the power balance is maintained at all times.

Primary and Secondary Control

To start with, the *primary reserve* is activated automatically by frequency fluctuations. Generators on primary control respond rapidly, typically within 30–60 seconds. Imbalances may occur due to the tripping of a thermal unit or the sudden disconnection of a significant load. An immediate response from primary control is required to reinstate the power balance, so that the system frequency becomes stable again. For this near-immediate response to power imbalances, adequate generation reserves must be available from generation units in operation.

The *secondary reserve* is activated either manually or automatically, within 10 to 15 minutes following frequency deviation from nominal frequency. It backs up the primary reserve and stays operational until long-term reserves take over, as illustrated in Figure H.2. The secondary reserve consists of a spinning reserve (hydro or thermal plants in part-load operation) and a

Figure H.1: Timescales for utility operations



Source: Parsons et al. (2003)

standing reserve (rapidly starting gas turbine power plants and load shedding).

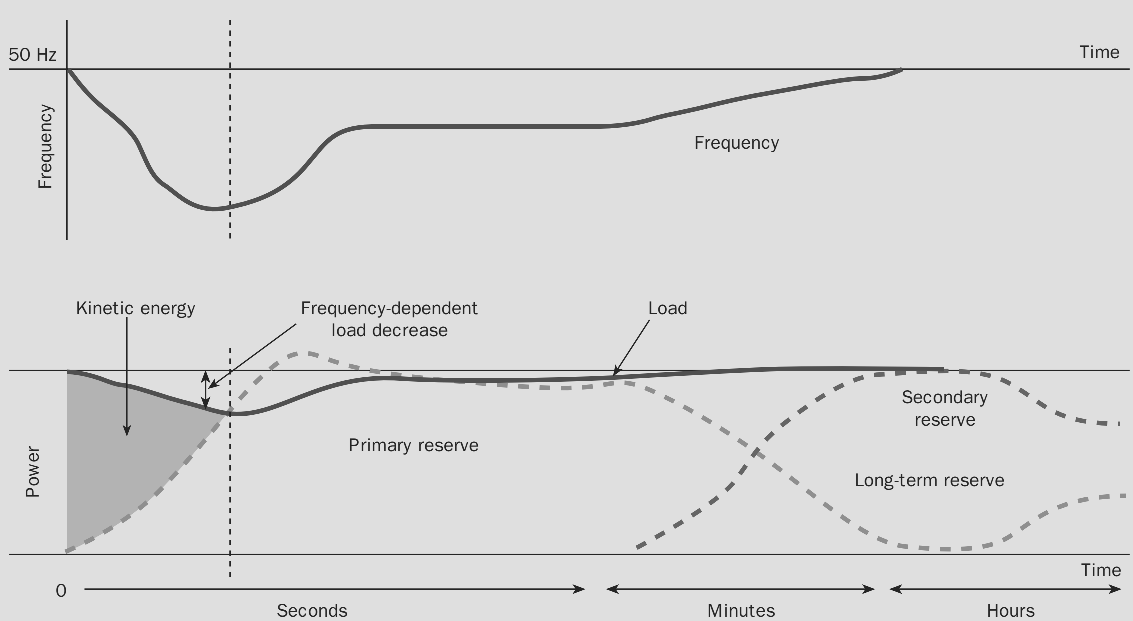
Since changes in loads and generation, which result in a power imbalance, are not predictable or scheduled in advance, primary and secondary controls operate continuously, to ensure that system frequency remains close to its nominal value.

Tertiary Control, Unit Commitment

Electrical power consumption varies by the minute, hour and day. As the power balance must be continuously maintained, generation is scheduled to match the longer-term variations. Such economic dispatch decisions are made in response to anticipated trends in demand (while primary and secondary control continues to respond to unexpected imbalances). For example, an increase in load usually occurs from around 7.00 am to midday, or early afternoon. After the daily peak is reached, the load typically falls over the next few hours, finally reaching a daily minimum late at night.

Some generators require several hours to get started and synchronised to the grid, which means that the generation available for the midday peak must have been initiated hours in advance, in anticipation of this peak. In many cases, the shutdown process is also lengthy, and units may require several hours of cooling prior to restarting. The decision to use this type of unit often means that it must run for several days, prior to shutting down, in order to be economically viable. This timescale is called 'unit commitment', and it can range from several hours to several days, depending on specific generator characteristics and operational practice.

Figure H.2: Activation of power reserves and frequency of power system as a function of time when a large power plant is disconnected from the power system



Source: Holttinen (2004a)

Task of the System Operator

During operational hours, the balancing task is usually taken over from individual power producers by the system operator. This is cost-effective, as the deviations of individual producers and loads equal out when aggregated, and only the net imbalances in the system area need to be balanced to control the frequency.

System operators have the information on schedules for production, consumption and interconnector usage. They either draw up these schedules themselves or obtain them from the electricity market or other parties involved (producers, balance responsible players or programme responsible parties) and they may also use online data and forecasts of load and wind power to assist in their operational duties. During operational hours, they follow the power system operation and call producers that have generators or loads as reserves, which can be activated depending on the need to balance power system net imbalances.

APPENDIX I: DETAILED COUNTRY REPORTS

Austria

MARKET STRUCTURE

With a share of 70 per cent RES-E (electricity from renewable energy sources) of gross electricity consumption in 1997, Austria was the leading EU Member State for many years. Large hydropower is the main source of RES-E in Austria. More recently, a steady rise in the total energy demand has taken place, and a decrease in the share of RES-E has been noted.

MAIN SUPPORTING POLICIES

Austrian policy supports RES-E through feed-in tariffs (FITs) that are annually adjusted by law. The responsible authority is obliged to buy the electricity and pay a FIT. The total available budget for RES-E support was decreased in May 2006, and tariff adjustments that are adjusted annually have been implemented. Within the new legislation, the annual allocated budget for RES support has been set at €17 million for 'new RES-E' up to 2011. This yearly budget is pre-allocated among different types of RES (30 per cent to biomass, 30 per cent to biogas, 30 per cent to wind, and 10 per cent to PV and the other remaining RES). Within these categories, funds will be given on a 'first come, first served' basis.

At present, a new amendment is being verified, suggesting an increase in the annual budget for support of new RES-E from €17 to €21 million. Consequently, the duration of FIT fuel-independent technologies might be extended to 13 years (now 10 years) and fuel-dependent technologies to 15 years (now 10 years), on behalf of the Minister of Economics. Moreover, investment subsidies of up to 15 per cent are in place for small hydro plants (> 1 MW). Emphasis is placed on 700 MW wind power, 700 MW small hydro power and 100 MW biomass.

FUTURE TARGETS

The RES-E target to be achieved in Austria by 2010 is 78.1 per cent of gross electricity consumption. In 2004, the share of renewable energy in gross electricity consumption reached 62.14 per cent, compared to 70 per cent in 1997.

Belgium

MARKET STRUCTURE

With a production of 1.1 per cent RES-E of gross electricity consumption in 1997, Belgium was at the bottom of the EU-15. National energy policies are implemented separately among the three regions of

Table I.1: Feed-in tariffs (valid for new RES-E plants permitted in 2006 and/or 2007) in Austria

Technology	Duration fixed years	2006–2007 fixed €/MWh
Small hydro	Year 10 and 11 at 75% and year 12 at 50%	31.5–62.5
PV systems		300–490
Wind systems		76.5 (2006); 75.5 (2007)
Geothermal energy		74 (2006); 73 (2007)
Solid biomass and waste with large biogenic fraction Note: Expressed values refer to 'green' solid biomass (such as wood chips or straw). Lower tariffs in case of sawmill, bark (–25% of default) or other biogenic waste streams (–40 to –50%)		113–157 (2006); 111–156.5 (2007) 64 (2006); 63 (2007) – max 50% for hybrid plants
Biogas		115–170 (2006); 113–169.5 (2007)
Sewage and landfill gas		59.5–60 (2006); 40.5–41 (2007)
Mid-scale hydro power plants (10–20 MW) and CHP plants receive investment support of up to 10% of the total investment costs		

the country, leading to different supporting conditions and separate, regional markets for green certificates. Policy measures in Belgium contain incentives to use the most cost-effective technologies. Biomass is traditionally strong in Belgium, but both hydro power and onshore wind generation have shown strong growth in recent years.

KEY SUPPORT SCHEMES

Two sets of measures are the key to the Belgian approach to RES-E:

1. Obligatory targets have been set (obligation for all electricity suppliers to supply a specific proportion of RES-E) and guaranteed minimum prices or 'fall-back prices' have been foreseen. In the Walloon region, the CWaPE (Commission Wallonne pour l'Energie) has registered an average price of €92/MWh per certificate during the first three months of 2006. In Flanders, the average price during the first half of 2006 has been around €110/MWh (VREG – Regulator in Flanders). In all three of the regions, a separate market for green certificates has been created. Due to the low penalty rates, which will increase over time, it is currently more favourable to pay penalties than to use the certificates. Little trading has taken place so far.
2. Investment support schemes for RES-E investments are available. Among them is an investment subsidy for PV.

FUTURE TARGETS

For Belgium, the target for RES-E has been set at 6 per cent of gross electricity consumption by 2010. Nationally, the target for renewable electricity is 7 per cent by 2007 in the Walloon region, 6 per cent by 2010 in Flanders and 2.5 per cent by 2006 in Brussels.

Bulgaria

MARKET STRUCTURE

Bulgaria is approaching its RES-E target for 2010. Large-scale hydro power is currently the main source of RES-E, but its technical and economic potential is already fully exploited. Good opportunities exist for biomass, since 60 per cent of land consists of agricultural

Table I.2: Implementation of RES-E in Belgium

			Flanders	Walloon	Brussels	Federal
Target	%		2010: 6%	2007: 7% RES-E & CHP	2004: 2.00% 2005: 2.25% 2006: 2.50%	
Duration	years		10	10		
Min price[1] (fixed)	€/MWh	Wind offshore	n/a	n/a	n/a	90[2]
	€/MWh	Wind onshore	80			50
	€/MWh	Solar	450	65 all RES-E		150
	€/MWh	Biomass and other	80			20
	€/MWh	Hydro	95			50
Penalty	€/MWh		€125 (2005–2010)	€100 (2005–2007)	€75 (2005–2006) €100 (2007–2010)	

Notes: [1]Min prices: for the Federal State the obligation to purchase at a minimum price is on the TSO; for the regions the obligation is on the distribution system operator (DSO).
[2]Wind, first 216 MW installed capacity: €107/MWh

land, and about 30 per cent is forest cover. Bulgaria's RES-E share of gross electricity consumption increased from 7.2 per cent in 1997 to 9.28 per cent in 2004.

KEY SUPPORT SCHEMES

RES-E policy in Bulgaria is based on the following key mechanisms:

- Mandatory purchase of electricity at preferential prices will be applied until the planned system of issuing and trading green certificates comes into force (expected by 2012).
- A Green Certificate Market is planned to be put in place from 2012. A regulation will determine the minimum mandatory quotas of renewable electricity that generation companies must supply as a percentage of their total annual electricity production. Highly efficient CHP will also be included under the tradable green certificate scheme. Under the green certificate scheme there will still be a mandatory purchase of electricity produced for production up to 50 MW.

FUTURE TARGETS

The RES-E target to be achieved in 2010 is about 11 per cent for electric energy consumption. The goal of Bulgaria's National Programme on Renewable Energy Sources is to significantly increase the share of non-hydroelectric RES in the energy mix. A total wind power capacity of around 2200–3400 MW could be installed. Solar potential exists in the East and South of Bulgaria, and 200 MW could be generated from geothermal sources.

Cyprus

MARKET STRUCTURE

In Cyprus, an issue regarding policy integration has been observed, since investments in a new fossil fuel power plant creating excess capacity are underway. Until 2005, measures that proactively supported renewable energy production, such as the New Grant Scheme, were not very ambitious. In Cyprus, targets

Table I.3: Actual mandatory purchase prices, determined by the State Energy Regulation Commission, in Bulgaria

Technology	Duration	Preferential price 2008[1]
Wind Plants with capacity up to 10 MW for all installation committed before 1 January 2006	12 years	€61.4/MWh
Wind new installations produced after 1 January 2006 effective operation >2250 h/a	12 years	€79.8/MWh
Wind new installations produced after 1 January 2006 effective operation <2250 h/a	12 years	€89.5/MWh
Hydro with top equaliser	12 years	€40.9/MWh
Hydro <10 MW	12 years	€43.6/MWh
Solar PV <5 kW	12 years	€400/MWh
Solar PV >5 kW	12 years	€367/MWh
Other RES	12 years	€40.6/MWh

Note: [1]VAT not included. Currently, the Bulgarian Government is considering whether to keep such differentiated levels of support for the different renewable resources, or to set a uniform preferential price for all types of RES.

Table I.4: FITs in Cyprus

Technology	Capacity restrictions	Duration fixed years	2005 fixed €/MWh	2006 fixed €/MWh	Note
Wind	No limit	First 5 yrs	92	92	Based on mean annual wind speed
		Next 10 yrs	48–92	48–92	Varies according to annual operation hours: < 1750–2000 h: €85–92/MWh 2000–2550 h: €63–85/MWh 2550–3300 h: €48–63/MWh
Biomass, landfill and sewage gas	No limit	15	63	63	A more generous scheme is currently being developed for biomass electricity; up to €128/MWh is expected, depending on the category of investment
Small hydro	No limit	15	63	63	
PV	Up to 5 kW	15	204	204	
	Without investment subsidy	15	x	337–386	Households receive higher tariff than companies

Note: Exchange rate €1 = CYP0.58.

are not being met. In 2006, a New Enhanced Grant Scheme was agreed upon. The leading RES in Cyprus is PV; wind power has a high potential.

KEY SUPPORT SCHEMES

RES-E policy in Cyprus is made up of the following components:

- The New Grant Scheme, valid from 2004 until 2006. A tax of 0.22c€/kWh on every category of electricity consumption is in place. The income generated by this tax is used for the promotion of RES.
- The New Enhanced Grant Scheme was installed in January 2006. Financial incentives (30–55 per cent of investments) in the form of government grants and FITs are part of this scheme.
- Operation state aid for supporting electricity produced by biomass has been suggested, and forwarded to the Commission for approval.

FUTURE TARGETS

The Action Plan for the Promotion of RES determines that the contribution of RES to the total energy consumption of Cyprus should rise from 4.5 per cent in 1995 to 9 per cent in 2010. The RES-E target to be achieved in 2010 from the EU Directive is 6 per cent. In Cyprus, the RES share of total energy consumption decreased from 4.5 per cent in 1995 to 4 per cent in 2002.

Czech Republic

MARKET STRUCTURE

The Czech Republic's legislative framework in relation to renewable energy sources has been strengthened by a new RES Act, adopted in 2005, and a Government Order regulating the minimum amount of biofuels or other RES fuels that must be available for motor fuel purposes. Targets for increasing RES in total primary energy consumption have been set at national level. The use of biomass in particular is likely to increase as a result of the new legislation.

KEY SUPPORT SCHEMES

In order to stimulate the growth of RES-E, the Czech Republic has decided on the following measures:

- A feed-in system for RES-E and cogeneration, which was established in 2000.

Table I.5: Key support schemes in the Czech Republic

Technology	Duration fixed years	Duration premium years	2005 fixed €/MWh	2006 fixed €/MWh	2006 premium €/MWh	2007 fixed €/MWh	2007 premium €/MWh
Wind energy	Equals the lifetime	Set annually	87	85	70	88–114	70–96
Small hydro (up to 10 MW)			68	81	49	60–85	23–48
Biomass combustion			84	79–101	46–68	84–121	44–81
Biomass co-firing with fossil fuels			17	*	19–41		9–55
Biogas			81	77–103	44–69	81–108	41–69
Geothermal electricity			117	156	126	161	125
PV			201	456	435	229–481	204–456

Note: * The Energy Regulatory Office (ERO) cannot reduce this by more than 5 per cent each year. Exchange rate €1 = CZK27.97.

- A new RES Act, adopted in 2005, extending this system by offering a choice between a FIT (a guaranteed price) or a 'green bonus' (an amount paid on top of the market price). Moreover, the FIT is index-linked whereby an annual increase of at least 2 per cent is guaranteed.

FUTURE TARGETS

A 15–16 per cent share of RES in total primary energy consumption by 2030 has been set as a target at national level. For RES-E, the target to be achieved is 8 per cent in 2010. The Czech Republic's RES percentage of total primary energy consumption is currently approximately 3 per cent. A very gradual increase can be observed in the RES-E share of gross electricity consumption (3.8 per cent in 1997, 4.1 per cent in 2004).

Denmark

MARKET STRUCTURE

Due to an average growth of 71 per cent per year, Danish offshore wind capacity remains the highest per capita in Europe (409 MW in total in 2007). Denmark is at present close to reaching its RES-E target for 2010. Two new offshore installations, each of 200 MW, are planned. RES other than offshore wind are slowly but steadily penetrating the market supported by a wide array of measures such as a new re-powering scheme for onshore wind.

KEY SUPPORT SCHEMES

In order to increase the share of RES-E in the overall electricity consumption, Denmark has implemented the following measures:

- A tendering procedure has been used for two new large offshore installations. Operators will receive a spot price and initially a settling price as well. Subsequent offshore wind farms are to be developed on market conditions.
- A spot price, an environmental premium (€13/MWh) and an additional compensation for balancing costs (€3/MWh) for 20 years is available for new onshore wind farms.
- Fixed FITs exist for solid biomass and biogas under certain conditions.
- Subsidies are available for CHP plants based on natural gas and waste.

Table I.6: Key support schemes in Denmark

Technology	Duration	Tariff	Note
Wind onshore	20 years	Market price plus premium of €13 / MWh	Additionally balancing costs are refunded at €3 / MWh, leading to a total tariff of approx. €57 / MWh
Wind offshore	50.000 h operation	€66–70 / MWh spot market price plus a €13 / MWh premium	A tendering system was applied for the last two offshore wind parks; balancing costs are by the owners
Solid biomass and biogas	10 years following 10 years	€80 / MWh €54 / MWh	New biogas plants are only eligible for the tariff if they are grid connected before end of 2008
Natural gas and waste CHP plants	20 years	Individual grant, depending on previous grants	Above 10 MW only; annual, non-production-related grant
	20 years	Three-time tariff	5–10 MW can choose the support scheme; below 5 MW only three-time tariff (receive a subsidy depending on when electricity production takes place, and this combined with the electricity market price, provides a three-tier tariff)
PV	Not determined	€200–250/MWh	'Meter running backwards' principle applied in private houses

FUTURE TARGETS

In Denmark, the RES-E target from the EU Directive is 29 per cent of gross electricity consumption by 2010. With an increase from 8.7 per cent RES-E in 1997 to 26.30 per cent in 2004, Denmark is nearing its target of 29 per cent RES-E of gross electricity consumption in 2010.

Estonia

MARKET STRUCTURE

Estonia has extensive fossil fuel reserves, including a large oil shale industry. However, the average annual growth rate for RES-E stands at 27 per cent. Estonia's largest RES potential is to be found in the biomass sector, but possibilities also exist in the areas of wind power, biogas electricity and small hydropower.

KEY SUPPORT SCHEMES

Estonian legislation relevant to RES-E includes:

- An obligation on the grid operator to buy RES-E providing that the amount 'does not exceed the network losses during the trading period' which came into force in 2005.
- A voluntary mechanism involving green energy certificates was also created by the grid operator (the state-owned Eesti Energia Ltd) in 2001.

Renewable electricity is purchased for a guaranteed fixed price of 81 EEKcents/kWh (5.2c€/kWh). Before, the Electricity Market Act (EMA) prices were linked to the sales prices of the two major oil-shale-based power plants.

The EMA states that the preferential purchase price for wind electricity is guaranteed for 12 years, but all current support mechanisms will be terminated in 2015. There is no information on legislation planned to replace this after 2015.

FUTURE TARGETS

In Estonia, the share of electricity produced from renewable energy sources is projected to reach 5.1 per cent in 2010. For RES-E, an average annual growth rate of 27 per cent has been registered between 1997 and 2004. Estonia's share of RES-E stood at 0.7 per cent in 2004, compared to 0.2 per cent in 1997. Dominant sources of RES-E in Estonia are solid biomass and small-scale hydropower.

Table I.7: Key support schemes in Estonia

Technology	Duration fixed years	2003–present fixed €/MWh
All RES	Wind: 12 Current support mechanisms will be terminated in 2015	52

Finland

MARKET STRUCTURE

Finland is nearing its RES-E target for 2010, and continues to adjust and refine its energy policies in order to further enhance the competitiveness of RES. Through subsidies and energy tax exemptions, Finland encourages investment in RES. Solid biomass and large-scale hydropower plants dominate the market, and biowaste is also increasing its share. Additional support in the form of FITs based on purchase obligations or green certificates is being considered for onshore wind power.

KEY SUPPORT SCHEMES

Finland has taken the following measures to encourage the use of RES-E:

- Tax subsidies: RES-E has been made exempt from the energy tax paid by end users.
- Discretionary investment subsidies: new investments are eligible for subsidies up to 30 per cent (40 per cent for wind).
- Guaranteed access to the grid for all electricity users and electricity-producing plants, including RES-E generators (Electricity Market Act – 386/1995).

Table I.8: Key support schemes in Finland

Technology	2003–present Tax reimbursement €/MWh
Wind and forest chip	6.9
Recycled fuels	2.5
Other renewables	4.2

FUTURE TARGETS

By 2025, Finland wants to register an increase in its use of renewable energy by 260 PJ. With regard to RES-E, the target to be met is 31.5 per cent of gross electricity consumption in 2010. With figures of 24.7 per cent in 1997 and 28.16 per cent in 2004, Finland is progressing towards its RES-E target of 31.5 per cent in 2010.

France

MARKET STRUCTURE

France has centred its RES approach around FITs on the one hand and a tendering procedure on the other. Hydropower has traditionally been important for electricity generation, and the country ranks second when it comes to biofuel production, although the biofuels target for 2005 was not met.

KEY SUPPORT SCHEMES

The French policy for the promotion of RES-E includes the following mechanisms:

- FITs (introduced in 2001 and 2002, and modified in 2005) for PV, hydro, biomass, sewage and landfill gas, municipal solid waste, geothermal, offshore wind, onshore wind and CHP; and
- a tender system for large renewable projects.

FUTURE TARGETS

The RES-E target from the EU Directive for France is 21 per cent RES-E share of gross electricity consumption in 2010. France's share of RES-E decreased from 15 per cent in 1997 to 12.64 per cent in 2004. France has vast resources of wind, geothermal energy and biomass, and wind power and geothermal electricity have shown growth. In addition, there is potential in the area of solid biomass.

Table I.9: Key support schemes in France

Technology	Duration	Tariff	Note
Wind onshore	10 years following 5 years	€82 / MWh €28–82/MWh	Depending on the local wind conditions
Wind offshore	10 years following 10 years	€130 / MWh €30–130 / MWh	Depending on the local wind conditions
Solid biomass	15 years	€49 / MWh	Standard rate, including premium up to €12 / MWh
Biogas	15 years	€45–57.2 / MWh	Standard rate, including premium up to €3 / MWh
Hydropower	20 years	€54.9–61 / MWh	Standard rate, including premium up to €15.2 / MWh
Municipal solid waste	15 years	€45–50 / MWh	Standard rate, including premium up to €3 / MWh
CHP plants		€61–95 / MWh	
Geothermal	15 years 15 years	€120 / MWh €100 / MWh	Standard rate In metropolis only Plus an efficiency bonus of up to €30 / MWh
PV	20 years 20 years	€300 / MWh €400 / MWh	In metropolis In Corsica, DOM and Mayotte Plus €250 / MWh and €150 / MWh respectively if roof-integrated

Germany

KEY ISSUES

Germany is an EU leader in wind utilisation, PV, solar thermal installations and biofuel production. Its onshore wind capacity covers approximately 50 per cent of the total installed capacity in the EU. A stable and predictable policy framework has created conditions favourable to RES penetration and growth. FITs for RES-E have proven a successful policy, leading to a very dynamic market for RES.

KEY SUPPORT SCHEMES

With the aim of promoting RES-E, Germany has introduced the following schemes through its Renewable Energy Act of 2004:

- FITs for onshore wind, offshore wind, PV, biomass, hydro, landfill gas, sewage gas and geothermal; and

Table I.10: Key support schemes in Germany

Technology	Duration	Tariff	Note
Wind onshore	20 years	€83.6 / MWh €52.8 / MWh	For at least 5 years Further 15 years, annual reduction of 2% is taken into account
Wind offshore	20 years	€91 / MWh €61.9 / MWh €30–130 / MWh	For at least 12 years Further 8 years, annual reduction of 2% is taken into account
Solid biomass and biogas	20 years 20 years	€81.5–111.6 / MWh €64.5–74.4 / MWh additional €20 / MWh	Annual reduction of 1.5% Annual reduction of 1.5% In CHP applications only
Hydropower up to 5 MW	30 years	€66.5–96.7 / MWh	Lower FITs also for hydro plants up to 150 MW
Geothermal	20 years	€71.6–150 / MWh	Annual reduction of 1% from 2010 on
PV	20 years	€406–568 / MWh	Annual reduction of 6.5%; prices vary depending on the location

Table I.11: Key support schemes in Greece

RES-E Technology	Mainland €/MWh	Autonomous islands €/MWh
Wind onshore	73	84.6
Wind offshore	90	90
Small hydro (<20 MW)	73	84.6
PV system (≤100 kWp)	450	500
PV system (>100 kWp)	400	450
Solar thermal power plants (≤5 MWp)	250	270
Solar thermal power plants (>5 MWp)	230	250
Geothermal	73	84.6
Biomass and biogas	73	84.6
Others	73	84.6

- large subsidised loans available through the DtA (Deutsche Ausgleichsbank) Environment and Energy Efficiency Programme.

FUTURE TARGETS

Overall, Germany would like to register a 10 per cent RES share of total energy consumption in 2020. The RES-E targets set for Germany are 12.5 per cent of gross electricity consumption in 2010 and 20 per cent in 2020. Substantial progress has already been made towards the 2010 RES-E target. Germany's RES-E share in 1997 was 4.5 per cent, which more than doubled to 9.46 per cent by 2004.

Greece

MARKET STRUCTURE

Hydropower has traditionally been important in Greece, and the markets for wind energy and active solar thermal systems have grown in recent years. Geothermal heat is also a popular source of energy. The Greek Parliament has recently revised the RES policy framework, partly to reduce administrative burdens on the renewable energy sector.

KEY SUPPORT SCHEMES

General policies relevant to RES include a measure related to investment support, a 20 per cent reduction of taxable income on expenses for domestic appliances or systems using RES, and a concrete bidding procedure to ensure the rational use of geothermal energy. In addition, an inter-ministerial decision was taken in order to reduce the administrative burden associated with RES installations.

Greece has introduced the following mechanisms to stimulate the growth of RES-E:

- FITs were introduced in 1994 and amended by the recently approved Feed-in Law. Tariffs are now technology-specific, instead of uniform, and a guarantee of 12 years is given, with a possibility of extension to up to 20 years.
- Liberalisation of RES-E development is the subject of Law 2773/1999.

FUTURE TARGETS

According to the EU Directive, the RES-E target to be achieved by Greece is 20.1 per cent of gross electricity consumption by 2010. In terms of RES-E share of gross electricity consumption, the 1997 figure of 8.6 per cent increased to 9.56 per cent in 2004.

Hungary

KEY ISSUES

After a few years of little progress, major developments in 2004 brought the Hungarian RES-E target within reach. Geographical conditions in Hungary are favourable for RES development, especially biomass.

Between 1997 and 2004, the average annual growth of biomass was 116 per cent. Whilst environmental conditions are the main barrier to further hydropower development, other RES such as solar, geothermal and wind energy are hampered by administrative constraints (for example the permit process).

KEY SUPPORT SCHEMES

The following measures exist for the promotion of RES-E:

- A feed-in system is in place. It has been using technology-specific tariffs since 2005, when Decree 78/2005 was adopted. These tariffs are guaranteed for the lifetime of the installation.
- A green certificate scheme was introduced with the Electricity Act (2001, as amended in 2005). This act gives the government the right to define the start date of implementation. At that time, FITs will cease to exist.

Nevertheless, from 2007, subsidies for cogeneration power and RES will be decreased, since national goals of production from RES were already achieved in 2005.

FUTURE TARGETS

The Hungarian Energy Saving and Energy Efficiency Improvement Action Programme expresses the country's determination to reach a share of renewable energy consumption of at least 6 per cent by 2010. The target set for Hungary in the EU Directive is a RES-E share of 3.6 per cent of gross electricity consumption. Progress is being made towards the 3.6 per cent RES-E target. Hungary's RES-E share amounted to 0.7 per cent in 1997 and 2.24 per cent in 2004.

Ireland

MARKET STRUCTURE

Hydro and wind power make up most of Ireland's RES-E production. Despite an increase in the RES-E share over the past decade, there is still some way to go before the target is reached. Important changes have occurred at a policy level. Ireland has selected the renewable energy feed-in tariff (REFIT) as its main instrument. From 2006 onwards, this new scheme is expected to provide some investor certainty, due to a

Table I.12: Key support schemes in Hungary

Technology		Duration fixed years	2005 fixed Ft./kWh	2005 fixed €/MWh	2006 fixed Ft./kWh	2006 fixed €/MWh
Geothermal, biomass, biogas, small hydro (<5 MW) and waste	Peak	According to the lifetime of the technology	28.74	117	27.06	108
	Off-peak		16.51	67	23.83	95
	Deep off-peak		9.38	38	9.72	39
Solar, wind	Peak		n/a	n/a	23.83	95
	Off-peak		n/a	n/a	23.83	95
	Deep off-peak		n/a	n/a	23.83	95
Hydro (>5 MW), cogeneration	Peak		18.76	76	17.42	69
	Off-peak		9.38	38	8.71	35
	Deep off-peak		9.38	38	8.71	35

Note: Exchange rate 1 Ft. = 0.004075 euros (1 February 2005) and 1 Ft. = 0.003975 euros (1 February 2006).

Table I.13: Key RES-E support schemes in Ireland

Technology	Tariff duration fixed years	2006 fixed €/MWh
Wind >5 MW plants	15	57
Wind <5 MW plants		59
Biomass (landfill gas)		70
Other biomass		72
Hydro		72

15-year FIT guarantee. No real voluntary market for renewable electricity exists.

KEY SUPPORT SCHEMES

Between 1995 and 2003, a tender scheme (the Alternative Energy Requirement – AER) was used to support RES-E. Since early 2006, the REFIT has become the main tool for promoting RES-E. €119 million will be used over 15 years from 2006 to support 55 new renewable electricity plants with a combined capacity of 600 MW. FITs are guaranteed for up to 15 years, but may not extend beyond 2024. During its first year, 98 per cent of all the REFIT support has been allocated to wind farms.

FUTURE TARGETS

The RES-E target for Ireland, set by the EU Directive, to be met by 2010, is 13.2 per cent of gross electricity consumption. The country itself would like to reach an RES-E share of 15 per cent by that time. The European Energy Green Paper, published in October 2006, sets targets over longer periods. In relation to Ireland, it calls for 30 per cent RES-E by 2020. Ireland is making some modest progress in relation to its RES-E target, with 3.6 per cent in 1997 and 5.23 per cent in 2004.

Italy

KEY ISSUES

Despite strong growth in sectors such as onshore wind, biogas and biodiesel, Italy is still a long way from the targets set at both national and European level. Several factors contribute to this situation. First, there is a large element of uncertainty, due to recent political changes and ambiguities in the current policy design. Second, there are administrative constraints, such as complex authorisation procedures at local level. And third, there are financial barriers, such as high grid connection costs.

In Italy, there is an obligation on electricity generators to produce a certain amount of RES-E. At present, the Italian Government is working out the details of more ambitious support mechanisms for the development and use of RES.

KEY SUPPORT SCHEMES

In order to promote RES-E, Italy has adopted the following schemes:

- Priority access to the grid system is guaranteed to electricity from RES and CHP plants.

Table I.14: Key support schemes in Italy

Technology	Capacity	Duration fixed years	2006 fixed €/MWh
Solar PV	<20 kW	20	44.5*
	≤50 kW		46
	50 < P < 1000 kW		49
Building-integrated PV	<20 kW		48.9*
	≤50 kW		50.6
	>50 kW		max 49 + 10%

Note: *From February 2006, these tariffs are also valid for PV with net metering ≤20 kW.

- An obligation for electricity generators to feed a given proportion of RES-E into the power system. In 2006, the target was 3.05 per cent. In cases of non-compliance, sanctions are foreseen, but enforcement in practice is considered difficult because of ambiguities in the legislation.
- Tradable green certificates (which are tradable commodities proving that certain electricity is generated using renewable energy sources) are used to fulfil the RES-E obligation. The price of such a certificate stood at €109/MWh in 2005.
- A FIT for PV exists. This is a fixed tariff, guaranteed for 20 years and adjusted annually for inflation.

FUTURE TARGETS

According to the EU Directive, Italy aims for a RES-E share of 25 per cent of gross electricity consumption by 2010. Nationally, producers and importers of electricity are obliged to deliver a certain percentage of renewable electricity to the market every year. No progress has been made towards reaching the RES-E target. While Italy's RES-E share amounted to 16 per cent in 1997, it decreased slightly to 15.43 per cent in 2004.

Latvia

MARKET STRUCTURE

In Latvia, almost half the electricity consumption is provided by RES (47.1 per cent in 2004), with hydropower being the key resource. The growth observed between 1996 and 2002 can be ascribed to the so-called 'double tariff', which was phased out in 2003. This scheme was replaced by quotas that are adjusted annually. A body of RES-E legislation is currently under development in Latvia. Wind and biomass would benefit from clear support, since the potential in these areas is considerable.

KEY SUPPORT SCHEMES

The two main RES-E policies that have been followed in Latvia are:

1. fixed FITs, which were phased out in 2003; and
2. a quota system, which has been in force since 2002, with authorised capacity levels of installations determined by the Cabinet of Ministers on an annual basis.

The main body of RES-E policy in Latvia is currently under development. Based on the Electricity Market Law of 2005, the Cabinet of Ministers must now develop and adopt regulations in 2006 to deal with the following areas:

- pricing for renewable electricity;
- eligibility criteria to determine which renewable energy sources qualify for mandatory procurement of electricity; and
- the procedure for receiving guarantees of origin for renewable electricity generated.

FUTURE TARGETS

According to the EU Directive, the RES-E share that Latvia is required to reach is 49.3 per cent of gross electricity consumption by 2010. Between 1997 and 2004, the Latvian RES-E share of gross electricity consumption increased from 42.4 per cent to 47.1 per cent.

Lithuania

MARKET STRUCTURE

Lithuania depends, to a large extent, on the Ignalina nuclear power plant, which has been generating 75–88 per cent of the total electricity since 1993. In 2004, Unit 1 was closed, and the shutdown of Unit 2 is planned before 2010. In order to provide alternative sources of energy, in particular electricity, Lithuania has set a national target of 12 per cent RES by 2010

Table I.15: Key support schemes in Lithuania

Technology	Duration fixed years	2002–present fixed €/MWh
Hydro	10	57.9
Wind	10	63.7
Biomass	10	57.9

(8 per cent in 2003). The implementation of a green certificate scheme was, however, postponed for 11 years. The biggest renewables potential in Lithuania can be found in the field of biomass.

KEY SUPPORT SCHEMES

The core mechanisms used in Lithuania to support RES-E are the following:

- FITs: in 2002, the National Control Commission for Prices and Energy approved the average purchase prices of green electricity. The tariffs are guaranteed for a fixed period of 10 years.
- After 2010, a green certificate scheme should be in place. The implementation of this mechanism has been postponed until 2021.

FUTURE TARGETS

At national level, it has been decided that the RES share of Lithuania's total energy consumption should reach 12 per cent by 2010. The RES-E EU Directive has fixed a RES-E target of 7 per cent of gross electricity consumption by 2010. In 2003, RES accounted for about 8 per cent of the country's energy supply. Between 1997 and 2004, an increase of 0.41 per cent in the RES-E share of consumption was noted (3.71 per cent in 2004 compared to 3.3 per cent in 1997).

Luxembourg

MARKET STRUCTURE

Despite a wide variety of support measures for RES and a stable investment climate, Luxembourg has not

Table I.16: Key support schemes in Luxembourg

		2001 to September 2005		From October 2005	
Technology	Tariff duration fixed years	Capacity	Tariff fixed €/MWh	Capacity	Tariff fixed €/MWh
Wind	10	Up to 3000 kW	25	<501 kW	77.6
Hydro					
Biomass				<501 kW	102.6 (77.6 + 25 for biomass)
Biogas (including landfill and sewage)					
Wind	10	x	x	500–10,001 kW	max 77.6 Lower for higher capacities
Hydro					
Biomass				500–10,001 kW	max 102.6 Lower for higher capacities
Biogas (including landfill and sewage)					
PV – municipalities	20	Up to 50 kW	250	No capacity restriction	280
PV – non-municipalities			450–550		560

made significant progress towards its targets in recent years. In some cases, this has been caused by limitations on eligibility and budget. While the electricity production from small-scale hydropower has stabilised in recent years, the contribution from onshore wind, PV and biogas has started to increase.

KEY SUPPORT SCHEMES

The 1993 Framework Law (amended in 2005) determines the fundamentals of Luxembourgian RES-E policy:

- Preferential tariffs are given to the different types of RES-E for fixed periods of 10 or 20 years. The feed-in system might be subject to change, due to further liberalisation of the sector.
- Subsidies are available to private companies that invest in RES-E technologies, including solar, wind, biomass and geothermal technologies.

FUTURE TARGETS

The RES-E target to be achieved in 2010, as set by the EU Directive, is 5.7 per cent of gross electricity consumption. A slight increase in Luxembourg's RES-E share can be noted. In 2004, the RES-E share amounted to 2.8 per cent of gross electricity consumption, compared to 2.1 per cent in 1997.

Malta

MARKET STRUCTURE

The market for RES in Malta is still in its infancy, and at present, penetration is minimal. RES has not been adopted commercially, and only solar energy and biofuels are used. Nevertheless, the potential of solar and wind is substantial. In order to promote the uptake of RES, the Maltese Government is currently creating a framework for support measures. In the meantime, it has set national indicative targets for RES-E lower than those agreed in its Accession Treaty (between 0.31 per cent and 1.31 per cent, instead of 5 per cent).

Table I.17: Key support schemes (FIT) in Malta

Technology	Support system	Comments
PV < 3.7 kW	€46.6 / MWh	Feed-in
Solar	5–15%	VAT reduction

Note: A framework for measures to further support RES-E is currently being examined.

KEY SUPPORT SCHEMES

In Malta, RES-E is supported by a FIT system and reduced value-added tax systems.

FUTURE TARGETS

The RES-E target set by the EU Directive for Malta is 5 per cent of gross electricity consumption in 2010. However, at national level, it has been decided to aim for 0.31 per cent, excluding large wind farms and waste combustion plants; or for 1.31 per cent in the event that the plans for a land-based wind farm are implemented. The total RES-E production in 2004 was 0.01 GWh and, therefore, the RES-E share of gross electricity consumption was effectively zero.

The Netherlands

MARKET STRUCTURE

After a period during which support was high but markets quite open, a system was introduced (in 2003) that established sufficient incentives for domestic RES-E production. Although successful in encouraging investments, this system, based on premium tariffs, was abandoned in August 2006 due to budgetary constraints. Political uncertainty concerning renewable energy support in The Netherlands is compounded by an increase in the overall energy demand. Progress towards RES-E targets is slow, even though growth in absolute figures is still significant.

MAIN SUPPORTING POLICIES

RES-E policy in The Netherlands is based on the 2003 MEP policy programme (Environmental Quality of Power Generation) and is composed of the following strands:

- Source-specific premium tariffs, paid for ten years on top of the market price. These tariffs were introduced in 2003 and are adjusted annually. Tradable certificates are used to claim the FITs. The value of these certificates equals the level of the FIT. Due to budgetary reasons, most of the FITs were set at zero in August 2006.
- An energy tax exemption for RES-E was in place until 1 January 2005.
- A guarantee of origin system was introduced simply by renaming the former certificate system.

The premium tariffs are given in Table I.18.

FUTURE TARGETS

In its climate policy, The Netherlands set a global target of 5 per cent renewable energy by 2010 and 10 per cent by 2020. According to the EU Directive, the RES-E share of The Netherlands should reach 9 per cent of gross electricity consumption in 2010. Between 1997 and 2004, progress was made towards the RES-E target. In 1997, the RES-E share was 3.5 per cent and by 2004 it had risen to 4.60 per cent.

Poland

MARKET STRUCTURE

Progress towards the RES-E target in Poland is slow and the penalties designed to ensure an increased supply of green electricity have not been adequately used. Despite the high potential of hydropower plants, they have not been fully used to date; biomass resources (in the form of forestry residues, agricultural residues and energy crops) are plentiful in Poland, and landfill gas is also promising.

MAIN SUPPORTING POLICIES

The Polish RES-E policy includes the following mechanisms:

- Tradable Certificates of Origin were introduced by the April 2005 amendment of the Law on Energy (1997).
- The Obligation for Power Purchase from Renewable Sources (2000, amended in 2003) involves a requirement on energy suppliers to provide a certain minimum share of RES-E (3.1 per cent in 2005, 3.6 per cent in 2006, 4.8 per cent in 2007 and 7.5 per cent in 2010). Failure to comply with this

Table I.18: Key support systems – premium tariffs in the Netherlands

Technology	Duration years	1 July–31 December 2004 premium, €/MWh	1 January 2005–30 June 2006 premium, €/MWh	Since August 2006 premium, €/MWh
Mixed biomass and waste	10	29	29	0
Wind onshore		63	77	0
Wind offshore		82	97	0
Pure biomass large scale >50 MW		55	70	0
Pure biomass small scale <50 MW		82	97	97*
PV, tidal and wave, hydro		82	97	0

Note: *Only for installations using biogas from manure digestion and having a capacity below 2 MW. Total premium is limited to €270 million for the complete duration period.

legislation leads, in theory, to the enforcement of a penalty; in 2005, this was not adequately enforced.
- An excise tax exemption on RES-E was introduced in 2002.

FUTURE TARGETS

Poland has a RES-E and primary energy target of 7.5 per cent by 2010. Steady but modest progress is being made with regard to the RES-E target, since the RES-E share of gross energy consumption was about 2.6 per cent in 2005, compared to 2.2 per cent in 2004 and 1.6 per cent in 1997. The potential of hydropower, biomass and landfill gas is high in Poland.

Portugal

MARKET STRUCTURE

The measures adopted so far in Portugal in relation to renewable energy constitute a comprehensive policy mix, complete with monitoring system. Between 1997 and 2004, Portugal has moved further away from its RES-E target. Due to the fact that this target is not entirely realistic, since it was based on the exceptional hydropower performance of 1997, Portugal is not expected to reach its target, even if measures are successful.

KEY SUPPORT SCHEMES

In Portugal, the following measures have been taken to stimulate the uptake of RES-E:
- Fixed FITs per kWh exist for PV, wave energy, small hydro, wind power, forest biomass, urban waste and biogas.
- Tendering procedures were used in 2005 and 2006 in connection with wind and biomass installations.
- Investment subsidies up to 40 per cent can be obtained.
- Tax reductions are available.

Table I.19: Key support schemes for RES-E in Portugal

Technology		Duration fixed years	2004 fixed €/MWh	2006[1] fixed €/MWh
Photovoltaics	<5 kW	15	450	450
Photovoltaics	>5 kW		245	310
Wave			247	n/a
Small hydro	<10 MW		78	75
Wind			90[2]	74
Forest biomass			78	110
Urban waste			70	75
Biogas			n/a	102

Notes: [1]Stated 2006 tariffs are average tariffs. Exact tariff depends on a monthly correction of the inflation, the time of feed-in (peak/off peak) and the technology used.

[2]Tariff only up to 2000 full load hours; 2006 tariff for all full load hours.

The Decreto Lei 33-A/2005 has introduced new FITs as listed in Table I.19.

FUTURE TARGETS

The RES-E target to be achieved by Portugal in 2010 is 39 per cent of gross electricity consumption. Portugal, which nearly met its RES-E target for 2010 in 1997, has now moved further away from this target. A sharp decline between 38.5 per cent in 1997 to only 23.84 per cent in 2004 was observed.

Romania

MARKET STRUCTURE

In terms of RES-E objective of gross electricity consumption, Romania is on target. In 2004, the majority of all RES-E was generated through large-scale hydropower. To a large extent, the high potential of small-scale hydropower has remained untouched. Between 1997 and 2004, both the level of production and the growth rate of most RES has been stable. Provisions

Table I.20: Key support schemes for RES-E in Romania

Period	Penalties for non-compliance
2005–2007	€63 / GC
2008–2012	€84 / GC (or CV – Certificat Verde)

The quota system is imposed on power suppliers, trading electricity between the producers and consumers.

for public support are in place, but renewable energy projects have so far not been financed.

KEY SUPPORT SCHEMES

Romania introduced the following measures to promote RES-E:

- A quota system, with tradable green certificates (TGCs) for new RES-E, has been in place since 2004, with a mandatory quota increase from 0.7 per cent in 2005 to 8.3 per cent in 2010–2012. TGCs are issued to electricity production from wind, solar, biomass or hydropower generated in plants with less than 10 MW capacity.
- Mandatory dispatching and priority trading of electricity produced from RES has existed since 2004.

FUTURE TARGETS

In Romania, the RES target to be achieved is 11 per cent of gross energy in 2010. The RES-E target was set at 33 per cent of gross electricity consumption in 2010; however, the share decreased from 31.3 per cent in 1997 to 29.87 per cent in 2004.

Slovakia

MARKET STRUCTURE

In the Slovak Republic, large-scale hydro energy is the only renewable energy source with a notable share in total electricity consumption. Between 1997 and 2004, this market share stabilised. The share taken up by small-scale hydro energy has decreased by an average of 15 per cent per year over the same period. An extended development programme, with 250 selected sites for building small hydro plants has been adopted. The government has decided to use only biomass in remote, mountainous, rural areas, where natural gas is unavailable. Between 1997 and 2004, the Slovak Republic moved further away from its RES target.

KEY SUPPORT SCHEME

RES-E policy in the Slovak Republic includes the following measures:

- A measure that gives priority regarding transmission, distribution and supply was included in the 2004 Act on Energy.
- Guarantees of origin are being issued.
- Tax exemption is granted for RES-E. This regulation is valid for the calendar year in which the facility commenced operation and then for five consecutive years.
- A system of fixed FITs has been in place since 2005.
- Subsidies up to €100.000 are available for the (re)construction of RES-E facilities.

Table I.21: Key support schemes (FITs) in the Slovak Republic

	2006		2007*	
Technology	fixed SKK/MWh	fixed €/MWh	fixed SKK/MWh	fixed €/MWh
Wind	2800	75.1	1950–2565	55–72
Hydro <5 MW	2300	61.7	1950–2750	55–78
Solar	8000	214.6	8200	231
Geothermal	3500	93.9	3590	101
Biogas	x	x	2560–4200	72–118
Biomass combustion	2700	72.4	2050–3075	58–87

Note: *Exact level of FIT depends on the exchange rate (here €1 = SKK35.458). The prices have been set so that a rate of return on the investment is 12 years when drawing a commercial loan. These fixed tariffs will be inflation adjusted the following year.

Decree No 2/2005 of the Regulatory Office for Network Industries (2005) set out the fixed FITs available for RES-E.

FUTURE TARGETS

In terms of its primary energy consumption, the Slovak Republic has fixed the target of 6 per cent renewable energy consumption by 2010. The target set by the EU Directive for RES-E is 31 per cent in 2010. Currently, renewable energy represents about 3.5 per cent of the total primary energy consumption in the Slovak Republic. Between 1997 and 2004, the share of RES-E decreased from 17.9 per cent to 14.53 per cent of gross energy consumption. In the Slovak Republic, the highest additional mid-term potential of all RES lies with biomass.

Slovenia

MARKET STRUCTURE

Slovenia is currently far from meeting its RES targets. Solid biomass has recently started to penetrate the market. Hydropower, at this time the principal source of RES-E, relies on a large amount of very old, small hydro plants; and the Slovenian Government has made the refurbishment of these plants part of the renewable energy strategy. An increase in capacity of the larger-scale units is also foreseen. In Slovenia, a varied set of policy measures has been accompanied by administrative taxes and complicated procedures.

KEY SUPPORT SCHEMES

In Slovenia, the RES-E policy includes the following measures:

- RES-E producers can choose to receive either fixed FITs or premium FITs from the network operators. A Purchase Agreement is concluded, valid for 10 years. According to the Law on Energy, the uniform annual prices and premiums are set at least once a year. Between 2004 and 2006, these prices stayed the same.
- Subsidies or loans with interest-rate subsidies are available. Most of the subsidies cover up to 40 per cent of the investment cost. Investments in rural

Table I.22: Key support schemes in Slovenia

Technology	Capacity	Duration: fixed years	Duration: premium years	2004–present: fixed SIT/MWh	premium SIT/MWh	fixed €/MWh	premium €/MWh
Hydro	<1 MW	After 5 years tariff reduced by 5%. After 10 years tariff reduced by 10%		14.75	6.75	62	28
	1–10 MW			14.23	6.23	59	26
Biomass	<1 MW			16.69	8.69	70	36
	>1 MW			16.17	8.17	68	34
Biogas (landfill and sewage gas)	<1 MW			12.67	–	53	–
	>1 MW			11.71	–	49	–
Biogas (animal waste)	–			28.92	–	121	–
Wind	<1 MW			14.55	6.55	61	27
	>1 MW			14.05	6.05	59	25
Geothermal	–			14.05	6.05	59	25
Solar	<36 kW			89.67	81.67	374	341
	>36 kW			15.46	7.46	65	31

areas with no possibility of connection to the electricity network are eligible to apply for an additional 20 per cent subsidy.

FUTURE TARGETS

At national level, a target to increase the share of RES in total primary energy consumption from 8.8 per cent in 2001 to 12 per cent by 2010 has been set. The RES-E target to be achieved in 2010, as a result of the EU Directive, is 33.6 per cent in Slovenia. At present, the contribution of RES to the national energy balance is about 9 per cent. In 2004, the Slovenian RES-E share of gross electricity consumption was 29.9 per cent. The potential of solid biomass is high, with over 54 per cent of land covered by forests.

Spain

MARKET STRUCTURE

Spain is currently far from its RES-E target. In 1997, a strong support programme in favour of RES was introduced. In 2004, hydropower still provided 50 per cent of all green electricity, while onshore wind and biomass had started penetrating the market. PV energy is also promising, with an average growth rate of 54 per cent per year. Proposed changes to the FITs and the adoption of a new Technical Buildings Code (2006) show increased support for biomass, biogas, solar electricity and solar thermal.

KEY SUPPORT SCHEMES

RES-E in Spain benefits from the following support mechanisms:

- A FIT or a premium price is paid on top of the market price. The possibility of a cap and floor mechanism for the premium is being considered. In the draft law published on 29 November 2006, reduced support for new wind and hydro plants and increased support for biomass, biogas and solar thermal electricity were proposed.
- Low-interest loans that cover up to 80 per cent of the reference costs are available.

Fixed and premium FITs for 2004, 2005 and 2006 are shown in Table I.23.

Table I.23: Fixed and premium FITs in Spain

Technology	Duration 2004–2006	2004 fixed €/MWh	2004 premium €/MWh	2005 fixed €/MWh	2005 premium €/MWh	2006 fixed €/MWh	2006 premium €/MWh
PV <100 kWp	No limit, but fixed tariffs are reduced after either 15, 20 or 25 years depending on technology	414.4	x	421.5	x	440.4	x
PV >100 kWp		216.2	187.4	219.9	190.6	229.8	199.1
Solar thermal electricity		216.2	187.4	219.9	190.6	229.8	199.1
Wind <5 MW		64.9	36.0	66.0	36.7	68.9	38.3
Wind >5 MW		64.9	36.0	66.0	36.7	68.9	38.3
Geothermal <50 MW		64.9	36.0	66.0	36.7	68.9	38.3
Mini hydro <10 MW		64.9	36.0	66.0	36.7	68.9	38.3
Hydro 10–25 MW		64.9	36.0	66.0	36.7	68.9	38.3
Hydro 25–50 MW		57.7	28.8	58.6	29.3	61.3	30.6
Biomass (biocrops, biogas)		64.9	36.0	66.0	36.7	68.9	38.3
Agriculture + forest residues		57.7	28.8	58.6	29.3	61.3	30.6
Municipal solid waste		50.5	21.6	51.3	22.0	53.6	23.0

FUTURE TARGETS

The Spanish *Plano de Energías Renovables 2005–2010* sets the goal of meeting 12 per cent of total energy consumption from RES in 2010. The target to be achieved in 2010, under the RES-E Directive, is 29.4 per cent of gross electricity consumption. The revised *Plano* of 2005 sets capacity targets for 2010, which include wind (20,155 MW), PV (400 MW), solar thermal (4.9 million m^2), solar thermal electric (500 MW) and biomass (1695 MW). In Spain, the RES-E share of gross electricity consumption was 19.6 per cent in 2004, compared to 19.9 per cent in 1997.

Sweden

MARKET STRUCTURE

Sweden is moving away from its RES-E target. In absolute figures, RES-E production decreased between 1997 and 2004, mainly due to a lower level of large-scale hydro production. However, other RES, such as biowaste, solid biomass, offshore wind and PV have shown significant growth. In Sweden, a comprehensive policy mix exists, with tradable green certificates as the key mechanism. This system creates both an incentive to invest in the most cost-effective solutions and uncertainty for investment decisions due to variable prices.

KEY SUPPORT SCHEMES

Swedish RES-E policy is composed of the following mechanisms:

- Tradable Green Certificates were introduced in 2003. The Renewable Energy with Green Certificates Bill that came into force on 1 January 2007 shifts the quota obligation from electricity users to electricity suppliers.
- The environmental premium tariff for wind power is a transitory measure and will be progressively phased out by 2009 for onshore wind.

FUTURE TARGETS

The RES-E target from the EU Directive for Sweden is 60 per cent of gross electricity consumption by 2010. The Swedish Parliament decided to aim for an increase in RES of 10 TWh between 2002 and 2010, which corresponds to a RES-E share of around 51 per cent in 2010. This deviates from the target originally set by the Directive. In June 2006, the Swedish target was amended to increase the production of RES-E by 17 TWh from 2002 to 2016. The Swedish share of RES-E for gross electricity consumption has decreased from 49.1 per cent in 1997 to 45.56 per cent in 2004 and approximately 38 per cent at the present time.

The UK

MARKET STRUCTURE

In the UK, renewable energies are an important part of the climate change strategy and are strongly supported by a green certificate system (with an obligation on suppliers to purchase a certain percentage of electricity from renewable energy sources) and several grants programmes. Progress towards meeting the target has been significant (electricity generation from renewable energies increased by around 70 per cent between 2000 and 2005), although there is still some way to go to meet the 2010 target. Growth has been mainly driven by the development of significant wind energy capacity, including offshore wind farms.

KEY SUPPORT SCHEMES

The UK's policy regarding renewable energy sources consists of four key strands:

1. Obligatory targets with tradable green certificate (ROC) system (a renewables obligation on all electricity suppliers in Great Britain). The non-compliance 'buy-out' price for 2006/2007 was set

Table I.24: Key support schemes in the UK

<table>
<tr><th rowspan="2">Year</th><th rowspan="2">Targets % supply of consumption target</th><th colspan="2">Non-compliance buy-out price</th><th>Amount recycled (England and Wales)</th><th colspan="2">Total ‘worth’ of ROC (England and Wales) (buy-out + recycle)</th></tr>
<tr><th>£/MWh</th><th>€/MWh*</th><th>£/MWh</th><th>£/MWh</th><th>€/MWh</th></tr>
<tr><td>2002–2003</td><td>3</td><td>X</td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td>2003–2004</td><td>4.3</td><td>30.51</td><td>44.24</td><td>22.92</td><td>53.43</td><td>77.47</td></tr>
<tr><td>2004–2005</td><td>4.9</td><td>31.39</td><td>45.52</td><td>13.66</td><td>45.05</td><td>65.32</td></tr>
<tr><td>2005–2006</td><td>5.5</td><td>32.33</td><td>46.88</td><td colspan="3" rowspan="11">Not yet known</td></tr>
<tr><td>2006–2007</td><td>6.7</td><td>33.24</td><td>48.20</td></tr>
<tr><td>2007–2008</td><td>7.9</td><td colspan="2" rowspan="9">Increases in line with retail price index</td></tr>
<tr><td>2008–2009</td><td>9.1</td></tr>
<tr><td>2009–2010</td><td>9.7</td></tr>
<tr><td>2010–2011</td><td>10.4</td></tr>
<tr><td>2011–2012</td><td>11.4</td></tr>
<tr><td>2012–2013</td><td>12.4</td></tr>
<tr><td>2013–2014</td><td>13.4</td></tr>
<tr><td>2014–2015</td><td>14.4</td></tr>
<tr><td>2015–2016</td><td>15.4</td></tr>
<tr><td>Duration</td><td colspan="6">One ROC is issued to the operator of an accredited generating station for every MWh of eligible renewable electricity generated with no time limitations</td></tr>
<tr><td>Guaranteed duration of obligation</td><td colspan="6">The Renewables Obligation has been guaranteed to run until at least 2027. Supply targets increase to 15.4% in 2015, and are guaranteed to remain at least at this level until 2027</td></tr>
</table>

at £33.24/MWh (approx. €48.20/MWh), which will be annually adjusted in line with the retail price index.

2. The climate change levy: RES-E is exempt from the climate change levy on electricity of £4.3/MWh (approx. €6.3 /MWh)
3. Grants schemes: funds are reserved from the New Opportunities Fund for new capital grants for investments in energy crops/biomass power generation (at least £33 million or €53 million over three years), for small-scale biomass/CHP heating (£3 million or €5 million), and planting grants for energy crops (£29 million or €46 million for a period of seven years). A £50 million (€72.5 million) fund, the Marine Renewables Deployment Fund, is available for the development of wave and tidal power.
4. Development of a regional strategic approach for planning/targets for renewable energies.

Annual compliance periods run from 1 April one year to 31 March the following year. ROC auctions are held quarterly. In the April 2006 auction over 261,000 ROCs were purchased at an average price of £40.65 (the lowest price for any lot was £40.60).

The following limits have been placed on biomass co-firing within the ROC:

- In the 2009–2010 compliance period, a minimum of 25 per cent of co-fired biomass must be energy crops;
- In 2010–2011, a minimum of 50 per cent of co-fired biomass must be energy crops;
- In 2011–2016, a minimum of 75 per cent of co-fired biomass must be energy crops; and
- After 2016, co-firing will not be eligible for ROCs.

FUTURE TARGETS

The RES-E target to be achieved by the UK in 2010 is 10 per cent of gross electricity consumption. An indicative target of 20 per cent for RES-E for 2020 has been set. After a relatively stable share in the early 2000s, growth over the past couple of years has been significant. In 2005, the share of renewable sources in electricity generation reached 4.1 per cent.

APPENDIX J: STUDIES ON EMPLOYMENT CREATION IN THE WIND ENERGY SECTOR

Table J.1: Summary of the main recent studies dealing with employment creation in the wind energy sector

Source	Title	Geographical coverage	Methodology	Main results
ADEME, 2008	'ADEME&Vous, Stratégie & Études. Maîtrise de l'énergie et développement des énergies renouvelables'	France	Net production/employment ratios (imports have been disregarded).	7000 jobs in the manufacturing of wind turbines and major sub-components; 500 in companies operating wind energy farms.
AEE, 2007	'Eólica 07. Todos los datos, análisis y estadísticas del sector eólico'	Spain	Questionnaires to Spanish wind energy companies, complemented by information from official tax-related registries.	There are more than 300 wind energy companies in Spain, creating 15,450 direct jobs and another 19,560 indirect jobs. This figure may go up to 58,800 if government objectives (20,000 MW in 2012) are achieved. 29.97% of the jobs are in the O&M sub-sector, 22.72% in the manufacturing of the machines, 19.42% in technical and engineering services, 9.12% in manufacturing, 3.24% in R&D, and 4.53% in 'others'.
Algoso and Rusch, 2004	'Job growth from renewable energy development in the Mid-Atlantic'	Mid-Atlantic States of the US: Maryland, Delaware, New Jersey and Pennsylvania	The number of jobs was calculated with the I-O Renewable Energy Policy Project. The technical coefficients were estimated by means of a survey sent to 19 wind energy companies in 2001. Indirect employment figures derive from the Texas Comptroller's office.	A capacity installed of 10,200 MW in 2015 would entail 11,100 year-long jobs in wind turbine manufacturing and installation; 740 permanent jobs in O&M and supporting areas; and around 12,700 indirect jobs. The jobs/MW ratio is 2.48. Choosing wind energy over a comparable amount of natural gas installations would create more than twice as many jobs.
DWIA, 2008	Sector statistics	Denmark	Questionnaires to Danish wind energy companies.	In 2006, 23,500 people worked for the wind energy sector (direct). 13,000 of these constitute direct employment in wind turbine and blade manufacturing companies.
European Commission, 2006a	European Commission's 2007 Impact Assessment on the Renewable Energy Roadmap	EU (27 Member States)	I-O tables, based on Green-X, PRIMES and ASTRA models.	Meeting the 20% RE target in 2020 will entail a net increase of 650,000 jobs in the EU, half of which may come from the biomass sector. The increase of RE will favour changes in the composition of the labour market, rather than its size.
European Parliament, 2007	'Employment potential of renewable forms of energy and increased efficiency of energy use'	EU	Meta-analysis of past employment studies.	A more rapid switch to renewables appears to have an unambiguous benefit in terms of overall employment. The growth of a particular segment of the clean energy business (renewables, energy efficiency or sustainable transport) is often partially dependent on growth in other areas, since the markets for products and technologies are linked. Workers that lose their jobs in the fossil fuel industry should have the opportunity to retrain for employment in the clean energy industry.

EREC, 2007	'New renewable energy target for 2020 – A renewable energy roadmap for the EU'	EU (15 Member States)	I-O tables, based on Saphire model.	The wind energy sector will account for around 184,000 jobs in 2010 (direct, indirect and induced effects) and 318,000 in 2020 (if the 20% RE target is reached).
EWEA, 2003	Survey for *Wind energy – The facts*	EU (15 Member States)	Survey of wind energy manufacturers, supplemented by the use of technical coefficients.	Direct employment in wind turbine manufacturing in Europe for 2002 accounted for 30,946 jobs; turbine installation for another 14,649; O&M for 2768.
EWEA and Greenpeace, 2005	'Wind Force 12: A blueprint to achieve 12% of the world's electricity from wind power by 2020'	World	Meta-analysis of past employment studies.	2.3 million jobs will be linked to the wind energy sector worldwide in 2020 if the 12% target is reached. 444,000 jobs in North America; 222,000 in Europe; 251,800 in Latin America; 44,400 in Africa, 44,400 in the Middle East; 325,600 in Eastern European and transition economies; 444,000 in China; 148,000 in East Asia; 266,400 in South Asia and 148,000 in OECD Pacific.
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2006	'Renewable energy: Employment effects. Impact of the expansion of renewable energy on the German labour market'	Germany	Comprehensive study, using a questionnaire and extensive theoretical models (I-O table). The study presents net results on the overall economy – direct, indirect and induced impacts.	The wind energy sector is responsible for around 64,000 jobs in Germany (2004 data). Half of them are direct jobs. By 2030, around 300,000 new jobs will be created in the renewable energy sources sector. The net impact can be situated between 80,000 and 130,000, depending on the future energy prices.
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2008	'Kurz – Und langfristige Auswirkungen des Ausbaus der erneuerbaren Energien auf den deutschen Arbeitsmarkt', interim report	Germany	Update of the 2006 report (questionnaire + I-O table).	84,300 employees in the wind energy sector by the end of 2007 (direct + indirect).
Kammen et al., 2004	'Putting renewables to work: How many jobs can the clean industry generate?'	EU and US	Meta-analysis of past employment studies.	The renewable energy sector generates more jobs per MW of power installed, per unit of energy produced and per dollar of investment than the fossil fuel-based energy sector. The distribution of employment benefits across regions can vary considerably. In the US, a 20% RE share by 2020 can create between 176,440 and 240,850 new jobs, as compared with a figure of 86,369 in the business-as-usual scenario. The jobs/MW ratio for wind power ranges between 0.71 and 2.79.

continued

Table J.1: (continued)

Source	Title	Geographical coverage	Methodology	Main results
Lehr et al., 2008	'Renewable energy and employment in Germany'	Germany	Comprehensive study, using a questionnaire and extensive I-O tables, INFORGE and PANTA RHEI models.	Gross employment figures in 2004: 63,944 workers. The wind sector lacks skilled personnel, but the situation is expected to improve in 2010. Global market share of wind energy products coming from Germany was 40% in 2004, and is expected to decrease to between 15 and 20% in 2020.
Pedden, 2005	'Analysis: Economic impacts of wind applications in rural communities'	US	Meta-analysis of 13 studies.	Wind installations create significant direct impact on the economies of the local communities, especially those with few supporting industries. The number of local and construction and operation jobs created by a wind energy installation depends upon the skills available in the local community. The jobs/MW ratio is highly variable: from 0.36 to 21.37.
Pfaffenberger et al., 2006	'Renewable energies – Environmental benefits, economic growth and job creation'	EU, with emphasis on Germany	Meta-analysis of previous studies.	All studies predict a growth in gross employment. The net employment impacts are substantially less, and can even be negative. None of the studies has taken into account the recent increase of energy prices, which will tend to increase the positive effect of RES on employment.
UNEP, ILO and ITUC, 2007	'Green jobs: Towards sustainable work in a low-carbon world', preliminary report	World	Meta-analysis of previous studies.	The wind energy sector created 300,000 jobs in 2006 worldwide. The jobs/MW ratio in manufacturing, construction and installation can be estimated between 0.43 and 2.51; 0.27 for O&M and 0.70 to 2.78 in total.
Whiteley et al., 2004	MITRE project 'Meeting the targets and putting RE to work' overview report	EU (15 Member States)	I-O tables, based on Saphire, model.	The wind energy sector will create between 162,000 (with current policies) and 368,000 (with advanced renewable strategies) new jobs in the EU (net effect; direct, indirect and induced jobs) by 2020. After 2010, the employment levels will be maintained only if the sector is capable of keeping its leading role and finding new markets outside the EU.

GLOSSARY

A

Active power is a real component of the apparent power, usually expressed in kilowatts (kW) or megawatts (MW), in contrast to **reactive power**.

Adequacy: a measure of the ability of the power system to supply the aggregate electric power and energy requirements of the customers within component ratings and voltage limits, taking into account planned and unplanned outages of system components. Adequacy measures the capability of the power system to supply the load in all the steady states in which the power system may exist, considering standard conditions.

Ancillary services are interconnected operations services identified as necessary to effect a transfer of electricity between purchasing and selling entities and which a provider of transmission services must include in an open access transmission tariff.

Annualised net metering is the same as **net metering**, but in this case the regulator averages a user's net electricity consumption or production over the span of one full year, rather than a shorter period.

ASACS: UK Air Surveillance and Control Systems.

Auxiliary costs are other than those of the turbine itself, in other words foundation, grid connection, electrical installation, road construction, financial charges and so on.

Availability describes the amount of the time that the wind turbine is actually functional, not out of order or being serviced.

B

Balance of Plant (BOP): the infrastructure of a wind farm project, in other words all elements of the wind farm, excluding the turbines. Includes civil works, **SCADA** and internal electrical system. It may also include elements of the grid connection.

Black start capability: some power stations have the ability to start up independently of a power grid. This is an essential prerequisite for system security, as these plants can be called on during a blackout to re-power the grid.

Boundary layer profile: see **wind shear profile**.

C

Capacity is the rated continuous load-carrying ability of generation, transmission or other electrical equipment, expressed in megawatts (MW) for **active power** or megavolt-amperes (MVA) for apparent power.

Capacity credit: a wind turbine can only produce when the wind blows and therefore is not directly comparable to a conventional power plant. The capacity credit is the percentage of conventional capacity that a given turbine can replace. A typical value of the capacity credit is 25 per cent (see **capacity factor**).

Capacity factor (load factor) is the ratio between the average generated power in a given period and the installed (rated) power.

Capital costs are the total investment costs of the turbine, including auxiliary costs.

Carbon dioxide (CO_2) is a naturally occurring gas, and also a by-product of burning fossil fuels and biomass, as well as land-use changes and other industrial processes. It is the principal anthropogenic greenhouse gas that affects the Earth's radiative balance.

Citizen engagement can be defined as being responsive to lay views and actively seeking the involvement of the lay public in policymaking and decision-making. Considered a central motif in public policy discourse within many democratic countries, it is acknowledged as an important component of good governance.

Climate change is a change of climate attributed directly or indirectly to human activity which alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.

Cogging: variation in speed of a generator due to variations in magnetic flux as rotor poles pass stator poles. Cogging in permanent magnet generators can hinder the start-up of small wind turbines at low wind speeds.

Community acceptance refers to the acceptance of specific projects at the local level, including affected populations, key local stakeholders and local authorities.

Contingency is the unexpected failure or outage of a system component, such as a generator, transmission line, circuit breaker, switch or other electrical element. A contingency may also include multiple components which are related by situations leading to simultaneous component outages.

Control area is a coherent part of the UCTE **Interconnected System** (usually concurrent with the territory of a company, a country or a geographical area, and physically demarcated by the position of points for measurement of the interchanged power and energy to the remaining interconnected network), operated by a single **transmission system operator (TSO)**, with physical loads and controllable generation units connected within the control area. A control area may be a coherent part of a **control block** that has its own subordinate control in the hierarchy of **secondary control**.

Control block comprises one or more **control areas**, working together in the **secondary control** function, with respect to the other control blocks of the **synchronous area** to which it belongs.

Costs of generated wind power: see **levelised costs**.

Curtailment means a reduction in the scheduled capacity or energy delivery.

D

D is the wind turbine rotor diameter (measured in metres).

Darrieus rotor is a sleek vertical axis wind turbine developed by French invertor G. J. M. Darrieus in 1929 based on aerodynamic profiles.

dB(A): The human ear is more sensitive to sound in the frequency range 1 kHz to 4 kHz than to sound at very low or high frequencies. Therefore, sound meters are normally fitted with filters adapting the measured sound response to the human ear.

Decibel (dB) is a unit of measurement that is used to indicate the relative amplitude of a sound or the ratio of the signal level such as sound pressure. Sound levels in decibels are calculated on a logarithmic scale.

Diffuser is a downwind device that diffuses the wind stream through a rotor.

Direct drive is a drive-train concept for wind turbines in which there is no gearbox and the wind turbine rotor is connected directly to a low-speed electrical generator.

Direct employment is the total number of people employed in companies belonging to a specific sector.

Discount rate is the interest rate used to calculate the present-day costs of turbine installations.

Distributed generation means single or small clusters of wind turbines spread across the landscape, in contrast to the concentration of wind turbines in large arrays or wind power plants.

Doppler shift principle: when a source generating waves moves relative to an observer, or when an observer moves relative to a source, there is an apparent shift in frequency. If the distance between the observer and the source is increasing, the frequency apparently decreases, while the frequency apparently increases if the distance between the observer and the source is decreasing. This relationship is called the Doppler effect (or Doppler shift) after Austrian physicist Christian Johann Doppler (1803–1853).

Doubly fed induction generator (DFIG) is an electrical machine concept in which variable-speed operation is provided by using a relatively small power electronic converter to control currents in the rotor, such that the rotor does not necessarily rotate at the synchronous speed of the magnetic field set up in the stator.

DTI: Department of Trade and Industry of the UK Government.

E

Efficiency for a turbine describes the amount of active electrical power generated as a percentage of the wind power incident on the rotor area.

Electricity demand is the total electricity consumption in GWh consumed by a nation annually.

Emissions are the discharges of pollutants into the atmosphere from stationary sources such as smokestacks, other vents, surface areas of commercial or industrial facilities, and mobile sources such as motor vehicles, locomotives and aircraft. With respect to climate change, emissions refer to the release of greenhouse gases into the atmosphere over a specified area and period of time.

Energy payback is the time period it takes for a wind turbine to generate as much energy as is required to produce the turbine in the first place, install it, maintain it throughout its lifetime and, finally, scrap it. Typically, this takes 2–3 months at a site with reasonable exposure.

Equivalent sound level (dB_{Leq}) quantifies the environmental noise as a single value of sound level for any desired duration. The environmental sounds are usually described in terms of an average level that has the same acoustical energy as the summation of all the time-varying events.

ETSU: Energy Technology Support Unit of the UK Government.

EWEA: European Wind Energy Association.

Experience curve relates the cumulative quantitative development of a product with the development of the specific costs. The more this product is produced, the more efficient the production process and the cheaper it becomes.

External costs are those costs incurred in activities which may cause damage to a wide range of receptors, including human health, natural ecosystems and the built environment, and yet are not reflected in the price paid by consumers.

F

Fault ride-through (FRT) is a requirement of many network operators, such that the wind turbine remains connected during severe disturbances on the electricity system, and returns to normal operation very quickly after the disturbance ends.

FINO 1 is an offshore research platform in the North Sea, off Germany.

Fuel cycle: the impacts of power production are not exclusively generated during the operation of the power plant, but also in the entire chain of activities needed for the electricity production and distribution, such as fuel extraction, processing and transformation, construction and installation of the equipment, and the disposal of waste. These stages, which constitute the chain of electricity production and distribution, are known as the fuel cycle.

Full load hours is the turbine's average annual production divided by its rated power. The higher the number of full load hours, the higher the tubine's production at the chosen site.

Furling is a passive overspeed control mechanism which functions by reducing the projected swept area, by turning the rotor out of the incident wind direction.

G

Gate closure is the point in time when generation and demand schedules are notified to the system operator.

Generation mix is the percentage distribution by technology (nuclear, thermal, large hydro, renewables) of MWs from operational generation plants.

Geographical information system (GIS) is a software system which stores and processes data on a geographical or spatial basis.

Giromill (or cycloturbine) is a vertical axis H-configuration wind turbine with articulating straight blades.

Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds. Human-made greenhouse gases in the atmosphere such as halocarbons and other chlorine- and bromine-containing substances are dealt with under the Montreal Protocol. Beside carbon dioxide, nitrous oxide and methane, the Kyoto Protocol deals with the greenhouse gases sulphur hexafluoride, hydrofluorocarbons and perfluorocarbons.

Grid-connected: a wind turbine is grid-connected when its output is channelled directly into a national grid (see also **stand-alone system**).

Grid reinforcement: a weak grid can be reinforced by up-rating its connection to the rest of the grid. The cost of doing this may fall to the wind farm developer.

H

High voltage (HV): typically 100 to 150 kV.

Horizontal axis wind turbine (HAWT): a wind turbine whose rotor axis is substantially parallel to the wind flow.

Hub: the rotating component of the wind turbine to which the rotor blades are fixed.

Hub height is the height of the rotor axis above the ground.

Hybrid power systems (HPS) are combinations of renewable technologies (such as wind turbines or solar photovoltaics) and conventional technologies (such as diesel generators) that are used to provide power to remote areas.

I

IEC: International Electrotechnical Commission.

Impact pathway approach is developed by ExternE to establish the effects and spatial distribution of the burdens from the fuel cycle to find out their final impact on health and the environment. Subsequently, the economic valuation assigns the respective costs of the damages induced by a given activity.

Independent power producer (IPP): a privately owned and operated electricity production company not associated with national utility firms.

Indirect employment refers to those employed in sectors and activities supplying intermediate products/components to, for example, wind turbine manufacturers. Indirect employment includes employment throughout the production chain.

Input-output: the national accounts of a country's or region's economic transactions keep track of all the inputs and outputs between economic sectors.

Installed capacity is the total MW of operational generation plant of a given technology.

Institutional capacity building refers to the process of creating more effective institutions through the increase of shared knowledge resources, relational resources and the capacity for mobilisation. It is usually related to the capacity to facilitate open policy- and decision-making processes (at national and local levels) that provide access to relevant stakeholders and room for various types of knowledge resources.

Institutional framework is a concept used to refer to the policy and regulatory elements affecting energy developments. In the wind energy context, this would include issues such as political commitment, financial incentives, planning systems, presence and roles of landscape protection organisations, and patterns of local ownership.

Interconnected system: two or more individual electric systems that normally operate synchronously and are physically connected via tie-lines (see also: **synchronous area**).

Interconnection is a transmission link (such as a tie-line or transformer), which connects two **control areas**.

Intermedial load refers to those electricity-generation technologies contributing to satisfy the demand in a range between the base load and peak load of the electricity system. A generating unit that normally operates at a constant output (amount of electricity delivered) takes all or part of the base load of a system. In contrast, a peak load unit is only used to reach specific peak periods of a few hours when the demand is high.

Investment costs are the costs of the turbine itself, including transport from the factory to the place where the turbine is erected.

ISO: International Organization for Standardization.

K

K-factor is a weighting of the harmonic load currents according to their effects on transformer heating. A K-factor of 1.0 indicates a linear load (no harmonics). The higher the K-factor, the greater the harmonic heating effects. The K-Factor is used by transformer manufacturers and their customers to adjust the load rating as a function of the harmonic currents caused by the load(s). Generally, only substation transformer manufacturers specify K-factor load de-rating for their products. So, for K-factors higher than 1, the maximum transformer load is de-rated.

Kilohertz (kHz) is a unit of measurement of frequency. It is a unit of alternating current (AC) or electromagnetic (EM) wave frequency equal to one thousand hertz (1000 Hz).

L

Learning rate is a learning curve parameter. It is estimated on available data for wind turbines and tells you the achieved reduction in specific production costs.

Levelised costs: the present-day average cost per kWh produced by the turbine over its entire lifetime, including all costs – (re-)investments, operation and maintenance. Levelised costs are calculated using the discount rate and the turbine lifetime.

Load means an end-use device or customer that receives power from the electricity system. Load should not be confused with demand, which is the measure of power that a load receives or requires.

Load-frequency control (LFC): see **secondary control**.

Local ownership is a way of community involvement based on the fact that local residents can own shares in and obtain personal benefits from local developments. There is a significant relationship between share ownership and positive attitudes towards wind farms, and local ownership and levels of wind implementation.

Low voltage (LV): below 1000 V.

Low-voltage ride-through (LVRT): see **fault ride-through**.

M

Market acceptance refers to the process by which market parties adopt and support (or otherwise) the energy innovation. Market acceptance is proposed in a wider sense, including not only consumers but also investors and, very significantly, intra-firm acceptance.

Medium voltage (MV): typically 10 to 35 kV.

Met mast: a mast or tower which carries meteorological instrumentation (typically wind speed transducers at several heights and wind direction, air temperature and pressure transducers).

Microvolts/cm (μVcm^{-1}) is a unit of measurement of electrical fields.

Millitesla (mT) is a unit of measurement of static magnetic fields.

Minigrid is a distribution network usually operating only at low voltage and providing electricity supply to a community. It is supplied by one or more diesel generators, wind turbines, mini-hydro generators or solar photovoltaics.

Minute reserve (15-minute reserve): see **tertiary control**.

Multiplier/multiplicator: for employment, this measures the direct and indirect employment effect of producing €1 million worth of output from the wind turbine manufacturing sector. Basically, it assumes that it is valid to multiply total wind turbine manufacturing in euros with a factor giving the necessary employment to produce this output. Series of multipliers for historical national account statistics exist.

N

N-1 criterion is a rule that requires elements remaining in operation after the failure of a single network element (such as a transmission line/transformer or generating unit, or in certain instances a busbar) to be capable of accommodating the change of flows in the network caused by that single failure.

(N-1)-safety means that any single element in the power system may fail without causing a succession of other failures, leading to a total system collapse. Together with avoiding constant overloading of grid elements, (N-1)-safety is a main concern for the grid operator.

Net metering is a policy implemented by some states and utilities to ensure that any extra electricity produced by an on-site generator, such a small wind system, can be sent back into the utility system, and where the owner is charged for energy on the basis of the net import.

Net transfer capacity is the maximum value of generation that can be wheeled through the interface between the two systems without leading to network constraints in either system, taking into account technical uncertainties about future network conditions.

Network power frequency characteristic defines the sensitivity, given in megawatts per hertz (MW/Hz), usually associated with a (single**) control area/block** or the entire **synchronous area**, which relates the difference between scheduled and actual **system frequency** to the amount of generation required to correct the power imbalance for that **control area/block** (or, vice versa, the stationary change of the **system frequency** in the case of a disturbance of the generation/load equilibrium in the **control area** without being connected to other **control areas**). It should not be confused with the K-factor (K). The network power frequency characteristic includes all active **primary control** and self-regulation of load and changes, due to modifications in the generation pattern and demand.

NIMBY is the acronym for 'not in my back yard' and refers to an explanation of the local rejection to technological projects. Recent research is questioning the traditional explanation of local rejection to technological projects based on the NIMBY concept, as this may be giving an incorrect or partial explanation of all the variables at stake.

Nitrogen oxide (NOx) is a product of combustion from transportation and stationary sources. It is a major contributor to acid depositions and the formation of ground-level ozone in the troposphere. It is formed by combustion under high pressure and high temperature in an internal combustion engine. It changes into nitrogen dioxide in the ambient air and contributes to photochemical smog.

Numerical weather prediction (NWP) means weather forecasting by computational simulation of the atmosphere.

O

Offshore: wind generation plant installed in a marine environment.

Offshore wind developments are wind projects installed in shallow waters off the coast.

Onshore wind developments are wind farms installed on land.

P

Participatory planning is a planning process open to higher levels of public engagement. Successful wind farm developments are linked to the nature of the planning and development process, and public support tends to increase when the process is open and participatory. Thus, collaborative approaches to decision-making in wind power implementation are suggested to be more effective than top-down imposed decision-making.

Permanent magnet generator (PMG) is a synchronous electrical generator design based on the use of permanent magnets on the rotor.

Photovoltaic generation (PV) is the generation of electricity from sunlight or ambient light, using the photovoltaic effect.

Point of common coupling (PCC) is the point on the public electricity network at which other customers are, or could be, connected. Not necessarily the same location as **point of connection**.

Point of connection (POC) is the point at which the wind farm electrical system is connected to the public electricity system.

Pollutant: a substance that is present in concentrations that may harm organisms (humans, plants and animals) or exceed an environmental quality standard. The term is frequently used synonymously with contaminant.

Power curve depicts the relationship between net electric output of a wind turbine and the wind speed measured at hub height on a 10-minute average basis.

Primary control (frequency control, primary frequency control) maintains the balance between generation and demand in the network, using turbine speed governors. Primary control is an automatic decentralised function of the turbine governor to adjust the generator output of a unit as a consequence of a frequency deviation/offset in the **synchronous area.** Primary control should be distributed as evenly as possible over units in operation in the synchronous area. The global primary control behaviour of an interconnection partner (**control area/block**) may be assessed by the calculation of the equivalent fallout of the area (basically resulting from the fallout of all generators and the self-regulation of the total demand). By the joint action of all interconnected undertakings, primary control ensures the operational reliability for the power system of the synchronous area.

Primary controller: decentralised/locally installed control equipment for a generation set to control the valves of the turbine, based on the speed of the generator (see **primary control**). The insensitivity of the primary controller is defined by the limit frequencies between which the controller does not respond. This concept applies to the complete primary controller-generator unit. A distinction is drawn between unintentional insensitivity, associated with structural inaccuracies in the unit, and a dead band set intentionally on the controller of a generator.

Primary control power is the power output of a generation set due **primary control**.

Primary control range is the range of adjustment of **primary control power**, within which **primary controllers** can provide automatic control, in both directions, in response to a frequency deviation. The concept of the primary control range applies to each generator, each **control area/block** and the entire **synchronous area**.

Primary control reserve: the (positive/negative) part of the **primary control range** measured from the working point prior to the disturbance up to the maximum **primary control power** (taking account of a limiter). The concept of the primary control reserve applies to each generator, each **control area/block** and the entire **synchronous area**.

Productivity is used here as employees per output unit in fixed prices. The 2 per cent increase in productivity used as a basic assumption implies that 2 per cent less people are needed to produce the same output every year. If additional cost reductions of turbines are assumed, this must partly be attributed to additional productivity increases further reducing the need for employees.

Progress ratio is related to the learning rate (see **learning rate**) – if the learning rate is 15 per cent, then the progress ratio is 85 per cent.

PX is a power exchange scheduling coordinator and is independent of system operators and all other market participants.

R

Rated wind speed is the lowest steady wind speed at which a wind turbine can produce its rated output power.

Reactive power is an imaginary component of the apparent power. It is usually expressed in kilo-vars (kVAr) or mega-vars (MVAr). Reactive power is the portion of electricity that establishes and sustains the electric and magnetic fields of alternating-current equipment. Reactive power must be supplied to most types of magnetic equipment, such as motors and transformers, and causes reactive losses on transmission facilities. Reactive power is provided by generators, synchronous condensers or electrostatic equipment such as capacitors and directly influences the electric system voltage. The reactive power is the imaginary part of the complex product of voltage and current.

Reinvestments are the costs of replacing a larger and more costly part of a turbine.

Reliability describes the degree of performance of the elements of the bulk electric system that results in electricity being delivered to customers within accepted standards and in the amount desired. Reliability at the transmission level may be measured by the frequency, duration and magnitude (or the probability) of adverse effects on the electric supply/transport/generation. Electric system reliability can be addressed by considering two basic and functional aspects of the electric system:

1. *adequacy*: the ability of the electric system to supply the aggregate electrical demand and energy requirements of customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements; and
2. *security*: the ability of the electric system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system elements.

Reynolds number: a dimensionless number describing the aerodynamic state of an operating aerofoil. The number is used along with the angle of attack to describe the limits of a particular aerofoil's lift-to-drag ratio and the conditions at which stall occurs. Small wind turbine aerofoils typically operate in a low Reynolds number range, from 0.150 to 0.5 million.

Rural electrification provides a regular supply of electricity to rural residents. It implies the extension of power lines to rural areas, or the use of stand-alone or isolated power systems.

S

Savonius rotor (S-rotor): a simple drag device producing high starting torque developed by the Finnish inventor Sigurd J. Savonius.

SCADA: see **supervisory control and data acquisition system**.

Secondary control is a centralised automatic function to regulate the generation in a **control area**, based on secondary control reserves in order to maintain its interchange power flow at the control programme with all other control areas (and to correct the loss of capacity in a control area affected by a loss of production) and, at the same time, in the case of a major frequency deviation originating from the control area, particularly after the loss of a large generation unit, to restore the frequency to its set value in order to free the capacity engaged by the **primary control** (and to restore the **primary control reserves**). In order to fulfil these functions, secondary control operates by the Network Characteristic Method. Secondary control applies to selected generator sets in the power plants comprising this control loop. Secondary control operates for periods of several minutes, and is therefore dissociated from primary control. This behaviour over time is associated with the PI (proportional-integral) characteristic of the secondary controller.

Secondary control range: the range of adjustment of the secondary control power, within which the secondary controller can operate automatically, in both directions at the time concerned, from the working point of the secondary control power. The positive/negative secondary control reserve is the part of the secondary control range between the working point and the maximum/minimum value. The portion of the secondary control range already activated at the working point is the secondary control power.

Security limits define the acceptable operating boundaries (thermal, voltage and stability limits). The **TSO** must have defined security limits for his own network and must ensure adherence to these security limits. Violation of these limits for a prolonged period of time could cause damage and/or an outage of another element that could cause further deterioration of system operating conditions.

Small-signal stability is the ability of the electric system to withstand small changes or disturbances without the loss of synchronism among the synchronous machines in the system, while having an adequate damping of system oscillations (sufficient margin to the border of stability).

Small wind turbine (SWT): a system with 300 m^2 rotor swept area or less that converts kinetic energy in the wind into electrical energy.

Social acceptance: in the energy and technology policy context, this concept refers to the responses of the lay public (including the hosting communities), and of stakeholders, such as industry and non-governmental, governmental and research organisations, to a specific energy innovation. The most recent and comprehensive approach to the social acceptance of renewable energies proposes the 'triangle model', integrating three key dimensions: socio-political acceptance, community acceptance and market acceptance.

Social trust: in technological and risk contexts, this refers to the level of trust individuals have towards organisations and authorities managing technological projects. It is increasingly regarded as a significant element in social reactions to technological developments. Trust can be created in careful, sophisticated decision-making processes that take time, but it can be destroyed in an instant.

Socio-political acceptance refers to the acceptance of both technologies and policies at the most general level. This general level of socio-political acceptance is not limited to the 'high and stable' levels of acceptance by the general public, but includes acceptance by key stakeholders and policymakers.

Stability is the ability of an electric system to maintain a state of equilibrium during normal and abnormal system conditions or disturbances.

Stand-alone systems are electric power systems independent of the network or grid, often used in remote locations where the cost of providing lines from large central power plants is prohibitive.

Static load flow calculations investigate the risk of system overload, voltage instability and **(N-1)-safety** problems. System overload occurs when the transmitted power through certain lines or transformers is above the capacity of these lines or transformers. System static voltage instability may be caused by a high reactive power demand from wind turbines. Generally speaking, a high reactive power demand causes the system voltage to drop.

Sulphur dioxide (SO_2) is a heavy, pungent, colourless gas formed primarily by the combustion of fossil fuels. It is harmful to human beings and vegetation, and contributes to the acidity in precipitation.

Supervisory control and data acquisition system (SCADA) is the wind farm monitoring system which allows the owner and the turbine manufacturer to be notified of faults or alarms, remotely start and stop turbines, and review operating statistics.

Surface roughness (Z_o) is a parameter used to describe the roughness of the surface of the ground.

Synchronous area: an area covered by **interconnected systems**. These systems' **control areas** are synchronously interconnected with the control areas of members of the association. Within a synchronous area the **system frequency** is commonly steady. A certain number of synchronous areas may exist in parallel on a temporary or permanent basis. A synchronous area is a set of synchronously interconnected systems that has no synchronous interconnections to any other interconnected systems.

System frequency is the electric frequency of the system that can be measured in all network areas of the **synchronous area** under the assumption of a coherent value for the system in a timeframe of seconds (with minor differences between different measurement locations only).

T

Tertiary control is any automatic or manual change in the working points of generators (mainly by rescheduling) in order to restore an adequate secondary control reserve at the right time. The power that can be connected automatically or manually under tertiary control in order to provide an adequate secondary control reserve is known as the tertiary control reserve or minute reserve. This reserve must be used in such a way that it contributes to the restoration of the **secondary control range** when required.

Thrust curve: a graph which shows the force applied by the wind at the top of the tower as a function of wind speed.

Tip speed: speed (in m/s) of the blade tip through the air.

Transformer: a piece of electrical equipment used to step up or down the voltage of an electrical signal. Most turbines have a dedicated transformer to step up their voltage output to the grid voltage.

Transient stability is the ability of an electric system to maintain synchronism between its parts when subjected to a disturbance of specified severity and to regain a state of equilibrium following that disturbance.

Transmission is the transport of electricity on the extra-high or high-voltage network (transmission system) for delivery to final customers or distributors. Operation of transmission includes as well the tasks of system operation concerning the management of energy flows, reliability of the system and availability of all necessary system services / **ancillary services**.

Transmission system operator (TSO): a company that is responsible for operating, maintaining and developing the transmission system for a **control area** and its **interconnections**.

Turbine lifetime is the expected total lifetime of the turbine (normally 20 years).

Turbulence intensity measures the 'roughness' of the wind, calculated for a time series of wind speed data, as the standard deviation divided by the mean wind speed.

U

UNEP-GEF: United Nations Environment Programme, Division of Global Environment Facility Coordination.

Unity (or harmony) with the landscape is the degree to which individuals perceive wind turbines to be integrated with the landscape. The perceived impact on landscape seems to be the crucial factor in public attitudes towards wind farms, and opposition to the visual despoliation of valued landscapes has been analysed as the key motivation for opposition to wind farms.

U-shape curve is a model stating that public attitudes towards wind farms change from being very positive, before the announcement of the project, to negative, when the project is announced, to positive again, after the construction. It is related to the familiarity factor, considered a key element in individuals' perception of technological developments.

Utility is the incumbent electricity supplier to end users (usually state-owned at some period), which may own and operate other electricity supply assets, including transmission networks and usually generation plant.

V

Value chain is the set of interconnected activities, consisting of discrete value-adding market segments, that comprise an industry. In the case of the wind energy industry, this may include (but is not restricted to) wind turbine manufacturing, project development, financing, asset ownership, operations and maintenance, and electricity distribution.

Value of statistical life (VSL) is an approach measuring a society's willingness to pay to avoid additional cases of death. This can be seen in spending for improved safety in the aircraft or car industry. In the EU and the US, values of between 1 and 10 million US$ or € per life saved have been found in different studies. Earlier versions of the ExternE project adopted a figure of US$3 million per life saved for VSL calculations. In these calculations the age of a person saved does not matter.

Vertical axis wind turbine (VAWT): a wind turbine with a vertical rotor axis.

W

Wind Atlas Analysis and Application Program (WAsP): a program for predicting wind climate and energy production from wind farms.

Wind farm design tool (WFDT): software to aid in the design and optimisation of a wind farm.

Wind home system (WHS): a wind-based system to provide basic lighting and entertainment needs to an individual home, with a capacity typically in the range of hundreds of watts.

Wind rose: a circular diagram giving a visual summary of the relative amounts of wind available in each of a number of direction sectors (often 12) at a given location, and the speed content of that wind.

Wind shear profile (α): the increase in wind speed with height above ground or sea level.

Wound rotor: a type of synchronous electrical machine in which the magnetic field on the rotor is established by passing a current through coils on the rotor. The alternative is to establish the magnetic field using permanent magnets (see **PMG**).

Wound rotor induction generator (WRIG): see **doubly fed induction generator**.

Y

Years of life lost (YOLL): the YOLL approach takes into account that due to different causes people in very different age groups may be at risk. In the case of a chronic disease leading to the death of very old people, only the years of life lost due to the disease, as compared to the average life expectancy, are taken into account. For each year of life lost, approximately 1/20th of the value of statistical life is used.

Z

Zone of visual influence (ZVI): the land area around a wind farm from which a specified number of wind turbines can be seen. Often presented as a map, with areas coloured depending on the number of turbines which can be seen.

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