Sea Wind Europe

GREENPEACE

Foreword

Europe faces an uncertain future. We live in a time of environmental and political instability. Climate change, the greatest environmental threat to humanity, is already manifesting devastating impacts across the European Union; meanwhile global tensions over natural resources and inequality are fuelling conflicts around the world.

As the expanding EU faces the twin threats of climate change and the need to guarantee energy security, it becomes increasingly clear that far-reaching changes in the energy system are going to be necessary. Oil dependency and the tension that it has caused are well documented. Coal, a major part of the old European energy mix and the most polluting fuel of all, is unusable in a low carbon economy.

Advocates of nuclear power, aware of its unpopularity and unsolved problems, nevertheless hold it up as a low-carbon option. But nuclear power has proved unreliable and expensive as well as dangerous; it is still unable to compete without huge subsidies. The threat of terrorism only compounds the risks. Nuclear power advocates say that we must expand its use despite the problems because renewable energy is unable to deliver on a large scale – that it cannot develop fast enough or be big enough to play a significant role in meeting Europe's energy demands.

Sea Wind Europe shows this to be false. **This report by international energy consultants Garrad Hassan shows how by 2020 one single source of renewable energy, offshore wind power, could provide 30% of the EU's electricity – just a fraction less than is currently supplied by nuclear power.** Success on this scale would not only deliver enormous environmental benefits from this clean, safe energy source, but would also generate an economic boom in Europe worth hundreds of billions of euros and creating up to 3 million jobs.

Renewable energy is already delivering electricity to millions of people worldwide, providing and sustaining hundreds of thousands of jobs, and offering the opportunities of a growing multi-billion euro market. The resources for wind, wave, tidal, biomass and solar generation are vast – easily enough to provide for the world's energy needs many times over. Europe is blessed with some of the richest renewable energy resources in the world and is already a world leader in harnessing them. Offshore wind is particularly suited to delivering very large-scale power to Europe.

The range of renewable energy technologies, combined with better energy efficiency, offer an immediate, clean, safe and effective answer to both climate change and energy security. By their nature, renewable energy sources are both indigenous and limitless. They are not dependent on uncertain fuel supplies or fluctuating prices. They are completely safe and are by far the most resilient technologies in the face of the impacts of climate change.

At this crucial and threatening time, it is Europe that must lead the way. Within the EU are the states and companies which lead the world in renewable energy development and in the fight to tackle climate change. Europe has the skills, the vision and more than enough renewable resources to prove these solutions for the rest of the world.

Other world leaders have faltered and failed to take the initiative. Their inaction in the face of the dangers places us all at risk. It is up to Europe to act. If the nations most enthusiastic for clean energy, if those most 'willing' in the world, with the best know-how and the most developed, vibrant renewable energy industry anywhere cannot make this clean energy vision a reality, then there is very real doubt as to whether anyone can. In that case climate change and conflict born from the desire for 'security' will hit hard and mercilessly.

Europe must rise to this challenge and lead the world.

The first and defining step towards European leadership in renewable energy must be the successful setting of an ambitious EU renewable energy target for 2020. This will set out the vision and create the framework within which our clean energy future can be delivered. *Sea Wind Europe* offers a clear blueprint of how to achieve its vision and outlines concrete policy measures that will give European renewables the foundation they need for success on a giant scale.

Energy is at the heart of today's most pressing global issues. The choices we make in the EU now, about where our energy will come from in future and how we will use it, have profound consequences for the lives, not just of every European, but of every person and species on the planet.

Gerd Leipold
Executive Director,
Greenpeace International

Executive summary

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1. Background

Sea Wind Europe is a vision for offshore wind energy. It demonstrates what could be possible for just one renewable energy technology – namely, to become a mainstay of Europe's electricity supply system.

Commissioned by Greenpeace, and written by wind energy consultants Garrad Hassan, *Sea Wind Europe* considers Greenpeace's question as to whether the supply of thirty per cent of current EU electricity demand – 720TWh/year – by 2020 is a viable aspiration for offshore wind. This implies the installation of 240GW of generating capacity by 2020, which is approximately ten times more than the present combined amount of installed on- and offshore wind power.

The report is deliberately bold, identifying at an early stage the necessary steps that need to be taken to remove any anticipated obstacles. In taking this approach, it tackles the belief held by some that renewables are a fine idea but cannot deliver practically at such a large scale, and that instead we must suffer environmental degradation as a consequence of our desire for electricity. This report shows that we should not have to compromise either the environment, or our social and economic well-being.

There are challenges, but with early action they should be surmountable. They are also almost certainly no greater than the challenges that would be presented by the 'business as usual' alternative.

Offshore wind energy is just one example of a renewable energy technology capable of making a significant contribution to Europe's electricity requirements. Energy efficiency also has an enormous role to play. Other renewables technologies, albeit at an earlier stage of development, offer similar prospects for large-scale deployment. Many of the conclusions drawn in *Sea Wind Europe* are equally applicable to these other technologies.

2 Analysis

What are the benefits?

It is well known that wind energy generates **electricity** while **avoiding adverse impacts on the environment.**

It also generates **jobs.** Studies have shown that offshore wind energy is likely to create jobs comparable in numbers to the conventional power sector. Also, because the manufacture of wind turbines, offshore support structures and other products utilises established skills and facilities from the heavy engineering sector, offshore wind energy can offer revitalisation for communities suffering from a decline in traditional manufacturing.

There is also demonstrable **public support** for wind energy. Surveys have shown approval ratings of over 70% to be nearly universal, with an average of 77%. Wind power is also a technology in which individuals have shown a willingness to invest through co-operatives and other investment vehicles. Middelgrunden, just off Copenhagen harbour, is the largest ever co-operatively owned wind farm.

What are the costs?

Onshore wind has shown dramatic cost reductions over the last decade, such that today facilities can be built at a lower per MW capital cost than all but gas-fired plant. In its operation, wind power is free from fuel price fluctuations and security of supply concerns. Offshore wind energy is at an earlier stage of development than onshore, but is still considered by bodies such as the International Energy Agency to be cheaper (even without consideration of external costs) than nuclear power. Furthermore, it is expected to achieve cost reductions with scale and with 'learning by doing'.

But this is not the full story. Environmental degradation entails costs which are either not attributed directly to those who cause them, or are not currently captured as economic costs at all. Termed 'externalities', these are costs to society as a whole, and include for instance pollution-related damage to ecosystems, with knock-on effects on human health and well-being. In comparison to conventional power plant, wind energy has negligible externalities. Governments are increasingly promoting wind energy and other renewables as cost-effective means to limit carbon emissions.

What are the key challenges?

The **technological** know-how for large-scale deployment of offshore wind is largely in place. The materials, facilities and skills required are also, for the most part, available for exploitation. Transfer of all of these elements from the offshore oil and gas and other sectors is required, and is beginning to happen.

Specific technological challenges such as the development of support structures for deeper waters will need to be overcome. Furthermore, existing companies exploiting what is at present a niche market will need to be ready to expand.

Sea Wind Europe-scale expansion of offshore wind energy will require changes in the physical grid network. If offshore wind is to grow significantly, it makes sense to consider the general expansion of the grid to meet demand in the context of plans for offshore wind energy. Adoption of new practices for operating the grid, as well as alterations to wind turbines such that they can integrate better into the grid, will also be required. These changes are necessary because wind energy is a new technology, and also because its output is intermittent.

For the most part, these changes employ existing solutions which have not been adopted simply because at low penetrations a sophisticated approach was not merited. However, evidence from Denmark suggests that high penetrations are achievable; moreover cost estimates of required grid reinforcement and system issues are often within the range of other project cost variances.

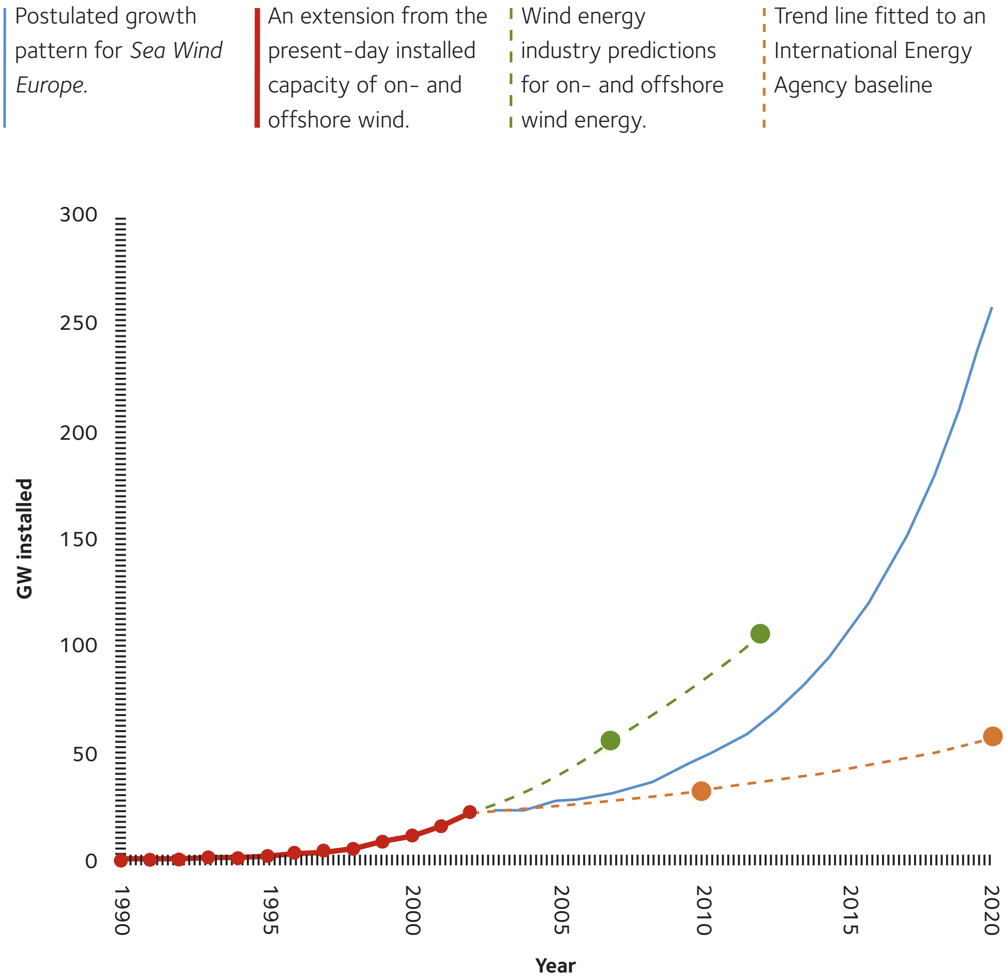
It is considered vital that commercial **finance** be made available to build offshore wind farms. For this to happen on a scale sufficient to achieve the *Sea Wind Europe* target, banks will need to come to regard offshore wind as a core part of their business. Many banks are active in lending to onshore wind, but lending to the offshore sector at the levels implied by *Sea Wind Europe* will require a step change in the activities of the investment community.

The desire to minimise risk means that the requirements of the finance community are relatively straightforward. Successful demonstration of offshore wind, in a range of environments, will provide assurance on technology risk. A long-term, stable market will provide comfort on the expected project returns.

What does Sea Wind Europe mean?

It is impossible to predict to 2020 where the offshore wind farms will be located, or the rate at which they will grow year on year. Nonetheless, it was considered very important, at least by way of example, to conceptualise the numbers in the report. This is achieved in two ways: by providing an illustrative growth curve for the *Sea Wind Europe* aspiration and putting this in the context of existing and established projections for growth of wind energy; and by using maps to illustrate the area of sea required to accommodate this growth.

Figure 1 Growth to 2020



3. Actions required

The culmination of analysis for *Sea Wind Europe* is the derivation of key actions for policy-makers, industry and other stakeholders. A key theme running all the way through is the need for a stable market, which gives financiers the confidence to lend and companies the confidence to expand.

Some of the key steps include:

- an ambitious EU-wide renewable energy target for 2020, building on, formalising and strengthening the existing Renewables Directive;
- the direction of financial assistance to address market failures and support renewable energy, including research, design and development support for the development and demonstration of offshore wind generation;
- action to encourage financial institutions to invest in very large offshore wind projects, including direction of investment or underwriting by government-controlled banks and credit agencies such as the EIB and ERBD; and
- an EU-wide strategic approach to the development of electricity grid capacity which anticipates the long-term requirements for offshore wind, including support, for example through the TEN programme, for the installation of offshore networks that will encourage optimal development of Europe's offshore wind resources.

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Glossary

AEY
Annual energy yield.

Capacity factor
Capacity factor is used to express the actual energy output of an electricity generator as a fraction of the energy that could theoretically be produced if it were to run constantly at 100% of its rated power. It is related to rated power and energy produced by the equation:
energy produced (kWh)
= capacity factor x rated capacity (kW) x time (hours).

CCGT
Combined cycle gas turbine.

C&I
Construction and installation.

Direct-drive
Describes a new type of wind turbine in which the rotor is connected directly on a single shaft to a special high-torque, low-speed generator without the use of a gearbox.

EBRD
European Bank for Reconstruction and Development.

EC
European Commission

EIB
European Investment Bank.

EIF
European Investment Fund.

EU 15
The current 15 Member States of the European Union, namely: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the United Kingdom.

EWEA
European Wind Energy Association.

GH
Garrad Hassan and Partners.

GP
Greenpeace UK.

Grid code
Grid codes detail the technical specifications for generators seeking to connect to the electrical network. Each code will be for defined parts of the network, usually either transmission or distribution for a country or a utility's jurisdiction.

IEA
International Energy Agency.

IGCC
Integrated gasification combined cycle.

IPCC
Intergovernmental Panel on Climate Change.

Kilowatt (kW), megawatt (MW), gigawatt (GW), terawatt (TW)
Units of power. A wind turbine is said to have a 'rated power' which is the maximum instantaneous power output for which it is designed. The units are in multiples of a thousand, and related to each other as follows:
1TW = 1,000GW = $1x10^6$MW = $1x10^9$kW.

Kilowatt hour (kWh), megawatt hour (MWh), gigawatt hour (GWh), terawatt hour (TWh)
Units of energy. A wind turbine's energy output is the sum of its actual instantaneous power output over time. So 1kWh is the energy produced by a 1kW generator operating at its rated power for an hour. The units are in multiples of a thousand, and related to each other as follows:
1TWh = 1,000GWh = $1x10^6$MWh = $1x10^9$kWh.

OECD
Organisation for Economic Co-operation and Development.

O&M
Operation and maintenance.

TEN
Trans-European Energy Networks. A European Commission programme which provides support funds for strategic electricity and gas links.

1. Introduction

1.1 Brief

Greenpeace (GP) has commissioned Garrad Hassan and Partners (GH) to provide a realistic vision for the development of offshore wind power to 2020. *Sea Wind Europe* considers whether an electricity output of 720TWh/year (just under a third of present demand among the EU 15 – the 15 current member states of the European Union) is a viable aspiration for 2020, and identifies the key actions that would be required to deliver this level of development.

In *Sea Wind Europe*, GH has drawn largely on existing information and knowledge – for the most part there is no proprietary analysis. The report attempts to highlight the most pertinent information for policy-makers, and assumes only a basic understanding of technical issues. Those with an interest in further technical detail are directed to the forthcoming European Commission (EC) publication, *Wind Energy, The Facts*, 2003 update[1], and the reference section at the end of this report.

1.2 Context

The majority of people in the EU are concerned about the environmental effects of conventional energy supplies, and are supportive of renewable energy as an alternative. This is borne out by numerous national, local and project-specific surveys, which consistently return approval ratings in excess of 70%.[2] The EC also recently reported the results of an EU 15 'Eurobarometer' survey of 16,000 people, *Energy: Issues, Options and Technologies*[3]. Among the findings were that 90% of those polled considered global warming a serious problem that requires immediate action, while nuclear power stations and/or waste management were almost universally cited as a priority safety concern. Furthermore, the survey found that renewables play a significant part in people's vision of the future, more so than any other conventional technology: 40% thought that renewables (other than hydropower) would be cheaper than conventional alternatives by 2050 (compared to 24% for hydropower, the next highest); 67% thought that non-hydro renewables would be best for the environment in 2050 (followed by 38% for hydro).

Promotion of renewable energy is an important part of the EC's energy policies. Europe is embarking on a transition in the way energy needs are met, driven by an environmental agenda. But there is ongoing discussion on the pace and nature of change which is desirable given economic and other considerations. Despite the fact that they offer an environmental solution, some people believe that there are practical reasons why renewables should not, and cannot, be developed on a large scale at the present time. These doubts include concerns about the cost and technical feasibility of large-scale renewables deployment.

Sea Wind Europe will address these doubts and fears in respect of renewables, and rationalise the challenges and risks that they do present in the context of the challenges and risks posed by the 'business as usual' scenario.

1.3 The scenario

Sea Wind Europe takes the aspiration of 720TWh/year of electricity from offshore wind by 2020 and examines what might be required to achieve this level of output.

Current EU 15 supply of electricity (as of 2002) is some 2,521TWh/year[4], and by 2020 the figure is forecast in *European Union Energy Outlook to 2020* to reach 3,124TWh/year[5]. If this forecast is accepted, then under our scenario offshore wind will be supplying 23% of total EU 15 demand in 2020. Such an achievement would place offshore wind in a market position as significant as that of conventional technologies today. Much stronger efforts in the EU towards improving energy efficiency could reduce future levels of demand. In such circumstances the offshore wind developed under the proposed scenario would meet a correspondingly greater portion of EU 15 energy needs.

Sea Wind Europe considers just one technology – offshore wind – as a case in hand, to examine whether large-scale deployment might be a reasonable aim for that technology alone. Offshore wind is a renewable energy technology which, given the right policies, is set for large-scale development in several European countries, and on a scale comparable to conventional power stations. *Sea Wind Europe* illustrates how entry into the energy mainstream might be achieved by this promising new technology. There is already a wealth of experience in onshore wind, which is being exploited in the development of other renewable energy technologies. Similarly, many of the conclusions drawn in this report are equally applicable to other renewable energy technologies.

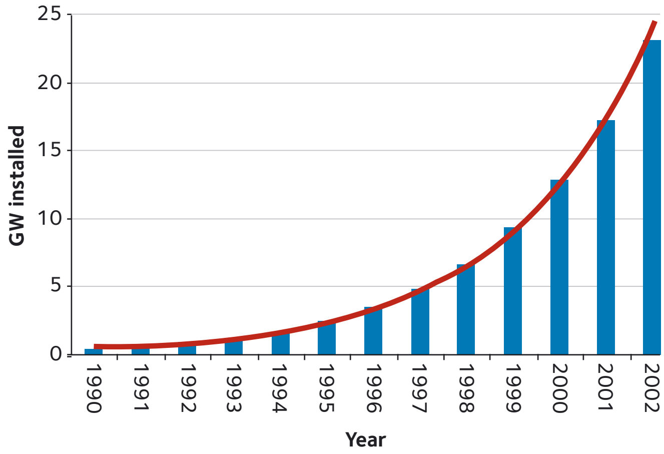
2. Growth rates

2.1 Historical growth

Figure 2.1 shows the cumulative wind energy capacity installed in the EU to 2002, the majority of which is onshore wind. It demonstrates an almost 33% year-on-year growth rate. The bars show actual installed capacity at the end of each year, the line is the fitted exponential curve. At the start of 2003 there was an installed capacity of 23GW.

Figure 2.1 European Union cumulative installed wind power capacity

Data up to 2001 from[6] and for 2002 from[7]



The EC-commissioned *European Union Energy Outlook to 2020* (published in 1999)[4] predicted an increase of 13.8GW of wind energy capacity over 10 years to 2010 – in fact there has been a growth of exactly this amount in less than half the time, between the years 1999 and 2002. Similarly, in *World Energy Outlook* (1998 edition)[8], the International Energy Agency (IEA) predicted 15GW of wind capacity in the Organisation for Economic Co-operation and Development (OECD) countries of Europe by 2010 – a figure which was reached and exceeded in 2001 in just the EU 15.

Wind energy industry predictions, showing greater confidence, have been closer to reality. The annual publication *International Wind Energy Development: World Market Update* by BTM Consult is the industry's most widely recognised forecast. In 1999[9] it predicted an installed European (including Eastern Europe) capacity of 21.8GW by 2003, and 40.7GW for 2008. So it is clear that wind energy has already exceeded some predictions, even those of the wind industry itself. The IEA and *European Union Energy Outlook* predictions were based largely on 'business as usual' models. Industry predictions have probably been more realistic as they have tended to be based on knowledge of specific national policies and a more pragmatic hands-on view.

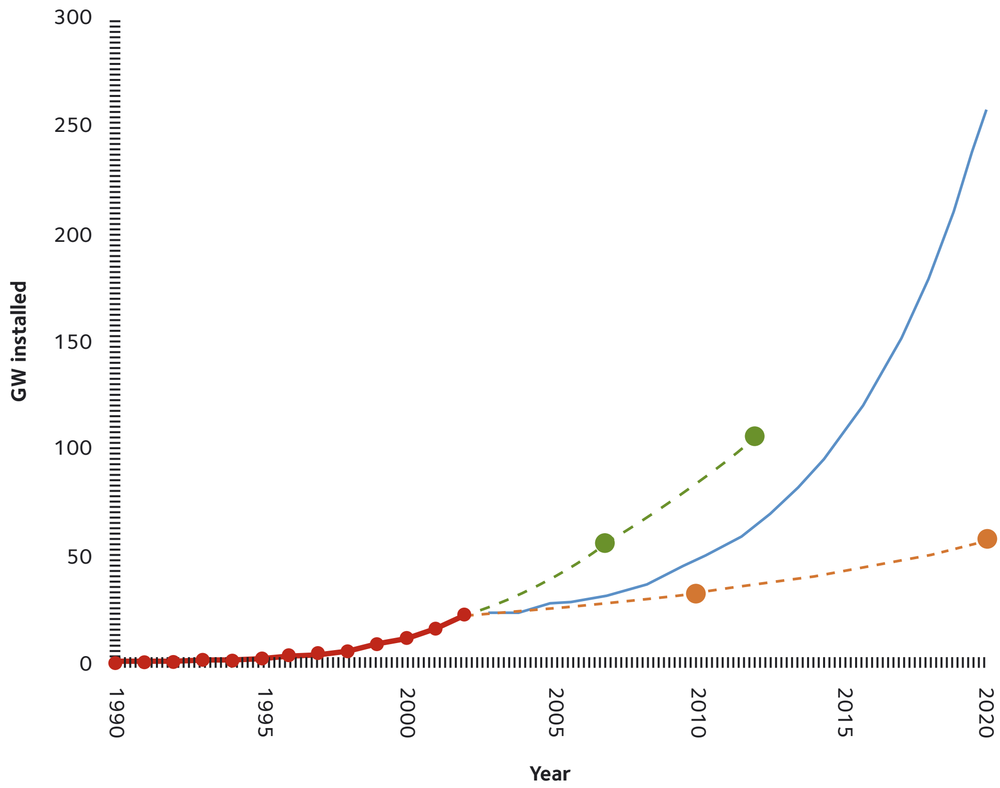
2.2 Expectations

If the 33% growth rate continues, wind power will reach just under 4TW by 2020. However, no one is predicting the continuation of this level of growth, which can be achieved from a low base but would be more difficult to sustain from the existing higher base and even more so from anticipated future levels. Rather growth is expected, even by the industry, to slow down over the next few decades but nevertheless remain substantial.

The IEA's latest predictions for wind energy, made in 2002[10], have been revised upwards. Its OECD Europe 'reference scenario' predicts 33GW of wind power for 2010, and 59GW for 2020 (figures for the EU 15, given separately for the first time in this report, are 33GW and 57GW respectively). An additional 'alternative policy scenario' in the 2002 edition of *World Energy Outlook* has a more optimistic outlook for renewables, taking into account not only established policies but some proposed ones. For Europe, this means achievement of the Renewables Directive targets (unlike the reference scenario, capacity predictions for wind energy are not provided for this scenario).

BTM's latest predictions, also made in 2002[11], forecast 59GW in Europe by 2007 (of which offshore contributes 5GW), and approximately 107GW by 2012. At its June 2003 conference, the European Wind Energy Association (EWEA) announced its new targets for 2020 as 180GW of wind power including 70GW of offshore capacity.

Figure 2.2 Installed wind power capacity growth to 2020



720TWh/year is equivalent to approximately 240GW of offshore wind capacity. Figure 2.2 below postulates a growth pattern for this amount of offshore wind power (the blue line), which is shown as an extension from the present-day installed capacity of on- and offshore wind (the red line). The same figure also shows trend lines fitted to the IEA's OECD Europe baseline (in orange) and BTM's predictions (in green) for on- and offshore wind power.

Clearly Figure 2.2 combines predictions which are not strictly comparable, but it is nonetheless useful in comparing the general scale of development expected. The vast majority of wind energy development to date has been within the EU 15 countries. The only major difference between BTM's and the IEA's predictions is the inclusion in BTM's predictions of some transition economies, which make a negligible contribution to the 2007 prediction (the contribution to the 2012 prediction is unknown).

The blue line for offshore wind in Figure 2.2 is simply an illustration of how offshore wind might grow by 240GW between 2003 and 2020. For 2003–05, it assumes that a base is established of nearly 5GW, after which offshore capacity grows at 40% per year to 2010, 26% per year from 2011 to 2015 and 23% per year from 2016 to 2020. This build-up in installation rates is considered more realistic than an alternative even year-on-year installation.

While the blue line shown in Figure 2.2 is well within BTM's total wind energy growth predictions, it is nonetheless a very ambitious rate of growth for offshore wind. It exceeds by 4.5GW BTM's offshore prediction for 2007. The later years, for which there are no comparable predictions, would require very substantial volume increases each year. BTM's predictions are based in part on expectations for policy measures in support of offshore wind, and clearly the growth rates postulated here require a very optimistic outlook on policy support for offshore wind in the EU. This is a key issue which is elaborated in later chapters.

2.3 Installation volumes

While the rate of offshore wind growth shown in Figure 2.2 is comparable to that achieved by onshore wind to date, the absolute volumes of installation required should also be considered. Installation of some 240GW of offshore wind power over 17 years translates, very approximately, into 48,000 5MW machines, at an average of a little under eight installed per day. Present-day offshore machines are rated at some 2–3.6MW. Machines of 5MW are expected to be available by 2010, and possibly higher ratings thereafter. An average 5MW rating between now and 2020 is therefore an approximation.

At an EU Member State level, for smaller onshore turbines, this level of turbine installation is already achieved in Germany, which in 2002 increased its capacity by 3,248MW. This is equivalent to an installation rate of approximately nine 1MW machines per day. BTM foresees installation of 11GW per year by 2012 for on- and offshore combined, which equates to, say, fifteen 2MW machines per day. The different turbine rating assumptions are a reflection of the timescale under consideration – it is the installation rate of machines which is important here.

Offshore is a challenging environment – in particular, the weather will limit construction windows. At present, a reasonable expectation might be installation of one turbine per day, per installation vessel. In order for this to be scaled up to level required for *Sea Wind Europe*, GH considers the number of projects coming forward to be the limiting factor.

Planning procedures are still being developed, especially for areas further offshore. These procedures will need to be finalised as a priority. No one Member State has plans in place for this kind of installation rate – namely eight machines per day. It is largely because of this limitation – the need to plan projects at a policy level – that EU-wide volume increases in the earlier years of the illustrative offshore wind scenario are shown as lower than the eight machines per day average, while later increases are correspondingly higher. These later, high installation levels are considered very ambitious and will require a significant and concerted effort now to set government plans and procedures in motion.

Some promise is shown by recent engineering concepts that may speed up the installation process. These are discussed in Chapter 5.

2.4 Conclusions

Predictions of installed wind energy capacity which rely on 'business as usual' models have tended to be pessimistic. The wind industry's own most recognised predictions, based on a pragmatic, policy-focused approach, have been much closer to reality. This suggests that specific wind or renewables policies are a crucial factor in achieving the high levels of growth seen to date.

Achievement of 240GW of offshore wind capacity by 2020 in the EU appears a reasonable expectation in the context of the growth of onshore wind power to date, and recent industry predictions for the growth of both onshore and offshore wind. Nevertheless, given the volume increases required, GH considers this figure to be an ambitious aim for offshore wind alone. This is in large part because planning procedures, policies and targets in place in Member States and at EU level do not currently provide for such a significant increase in offshore wind.

There is therefore an urgent need for early action to establish the necessary policy, planning and consenting framework, if these ambitious aspirations for offshore wind are to be realised.

4.5MW turbine

3. Resource and development scale

3.1 Resource estimation

On a broad scale, the potential wind resource can be modelled using meteorological data as an input, and taking into account the effects of elevation, topography and other factors. Typically, such models allow derivation of, at least, wind speed estimates for a specified height, as a gridded or contour dataset[12]. By combining this with assumptions about the technology and its deployment density (the number of machines installed per unit area), an energy (usually kWh per annum) estimate can be produced. Wind is ubiquitous, and although there are wind speeds below which exploitation would not be economic, other considerations are often the limiting factor on deployment.

Most wind energy resource studies start with a top-level theoretical resource that is progressively reduced through consideration of constraints, ranging from geographically delineated protected areas to economic cut-offs. This is usually computed in a Geographical Information System (GIS), sometimes supplemented by other processing. There are inevitably limits to the extent to which these modelling exercises can reflect reality – data availability is the main limitation, but there are also some constraints that simply cannot be modelled accurately.

Such studies are useful in estimating upper bounds on deployment, the effects of known constraints, interactions between constraints and likely patterns of development. A GIS also helps visualisation of development scale. Because technology undergoes progressive development, and the nature of constraints evolves as solutions are found and new factors emerge, resource estimates tend to have a time-limited validity.

In this chapter some previous resource estimates are briefly reviewed. Existing estimates are revised, using different assumptions as to technology and technical constraints. A GIS is used to visualise the scale of development implied by a 720TWh/year target.

3.2 Previous estimates

A 1995 study for the Commission, *Study of Offshore Wind Energy in the EC* by GH and Germanischer Lloyd[13], estimated a total EU (excepting Sweden) resource of 3,029TWh/year. This represents the resource within 30km of shore and in areas with water depths of no greater than 40m. Where data were available, it also excludes areas around oil and gas infrastructure and cables, protected areas, military areas and marine traffic routes.

Wind Force 12[14], a 2003 Greenpeace/EWEA publication, further constrains the 1995 estimate by assuming development only in waters up to 20m depth, and largely in the 10–30km offshore range, at a reduced density. These very conservative assumptions lead to an estimated resource of 313.6TWh/year.

3.3 Current approach

GIS was employed in this study to gain an appreciation of the scale of development implied, through the use of maps, as opposed to any more sophisticated attempt to estimate the total resource or to show likely deployment locations. Scenario-based maps illustrating a build-up to 240GW installed capacity are shown in Section 3.4. The process by which these maps were developed is explained in full in Appendix A. The key assumptions are summarised below.

A wind speed GIS layer was derived primarily from the previously mentioned EC study dataset[13]. Assuming a medium-range deployment density[15] of 8MW/km^2 and a power curve from a typical modern offshore wind turbine, an annual energy yield (AEY) was derived for each GIS grid square.

Sea depth and distance to shore were the key economic and technical factors used to determine potential resource and possible siting areas. The ranges assumed to be accessible were increased over the course of the period to 2020 (as described in the scenarios below).

Where digital data were available, specific potential constraints were taken into account in the GIS. For traffic zones, oil and gas platforms, pipelines and cables, any kilometre square of the GIS in which their presence was recorded was excluded. For traffic zones, a one kilometre square buffer zone was also excluded.

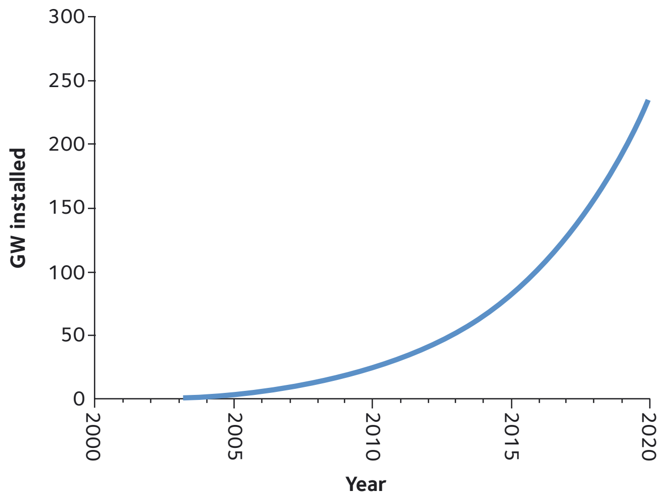
It is noted that, when investigating a potential site, developers must consider in detail a wide range of constraints. Potential impacts, and their magnitude, are subject to in-depth assessment in both the Strategic Environmental Assessment and the Environmental Impact Assessment processes. The former is an assessment of government plans and policies carried out prior to their implementation, the latter an impact assessment carried out by a developer in support of an application for project consent.

Taking the exclusions described, and within bounding assumptions for scenarios to 2010, 2015 and 2020, wind farms were placed from judgement offshore of coastal EU 15 countries. This judgement included visual checking against Admiralty Charts for any obvious constraints, knowledge of existing wind farms and planned developments, and feedback from Greenpeace offices throughout Europe. This was a purely indicative approach to show development scale. There is no suggestion at all that the resulting locations are where wind farms should, or could, locate.

Assuming approximately the growth pattern of offshore wind postulated in the previous chapter (see Figure 2.2) and shown below in Figure 3.1, three sequential scenarios were considered. These were as follows:

2010: In addition to the considerations described above, wind farms were limited to areas within a band 5–30km from shore, and within 30m depth. The 5km boundary was to

Figure 3.1 Postulated growth of offshore wind power capacity to 2020



reflect a general move by some countries to impose a coastal buffer zone for very large offshore wind farms on visual grounds. The 30km from shore and 30m depth constraints reflect a combination of anticipated technical and cost-related limitations to 2010. On technical grounds, wind farms were placed to avoid locations that experience particularly extreme weather conditions.

2015: As offshore wind farms move into more challenging environments, they might first be expected to move further offshore and to slightly deeper locations, in relatively less exposed areas (rather than shallow but exposed locations closer to shore). For this intermediate scenario, additional area was therefore released by relaxing the depth limitation to 50m and the distance limitation to 5–40km.

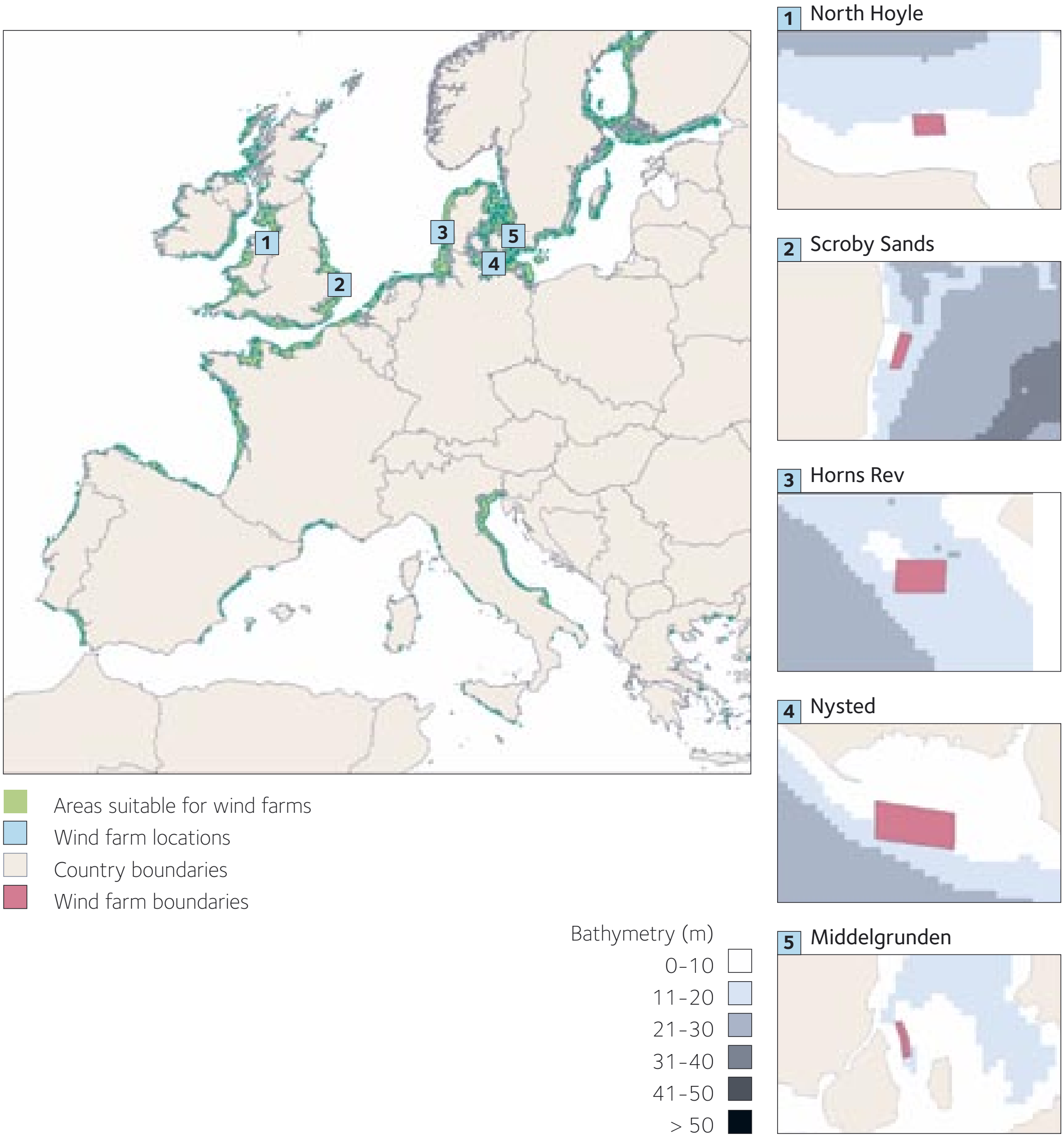
2020: By 2020, it is considered that exposed locations may become cost-effective, and hence they are now released for development, as well as areas outside the 40km from shore constraint, and at depths of up to 100m. Even if technology allows, deeper, more exposed and further offshore locations are still likely to be more expensive, and thus a site which combines all three – deep, far off, and exposed – is not represented in this scenario.

3.4 Maps

Figure 3.2 shows Europe's largest commercial-scale offshore wind farms, both installed and under construction, to scale, as a benchmark for the later scenario-based maps. Of these wind farms, North Hoyle, Nysted, Middelgrunden and Horns Rev are operational, and photographs of the latter two projects are shown in Figure 3.3.

Figures 3.4 to 3.10 show the results of the wind farm scenario representation. The gradated blue delineates the area released by the depth and distance from shore limitations imposed in each of the 2010, 2015 and 2020 scenarios. The gradated pink shows wind farms placed for each scenario.

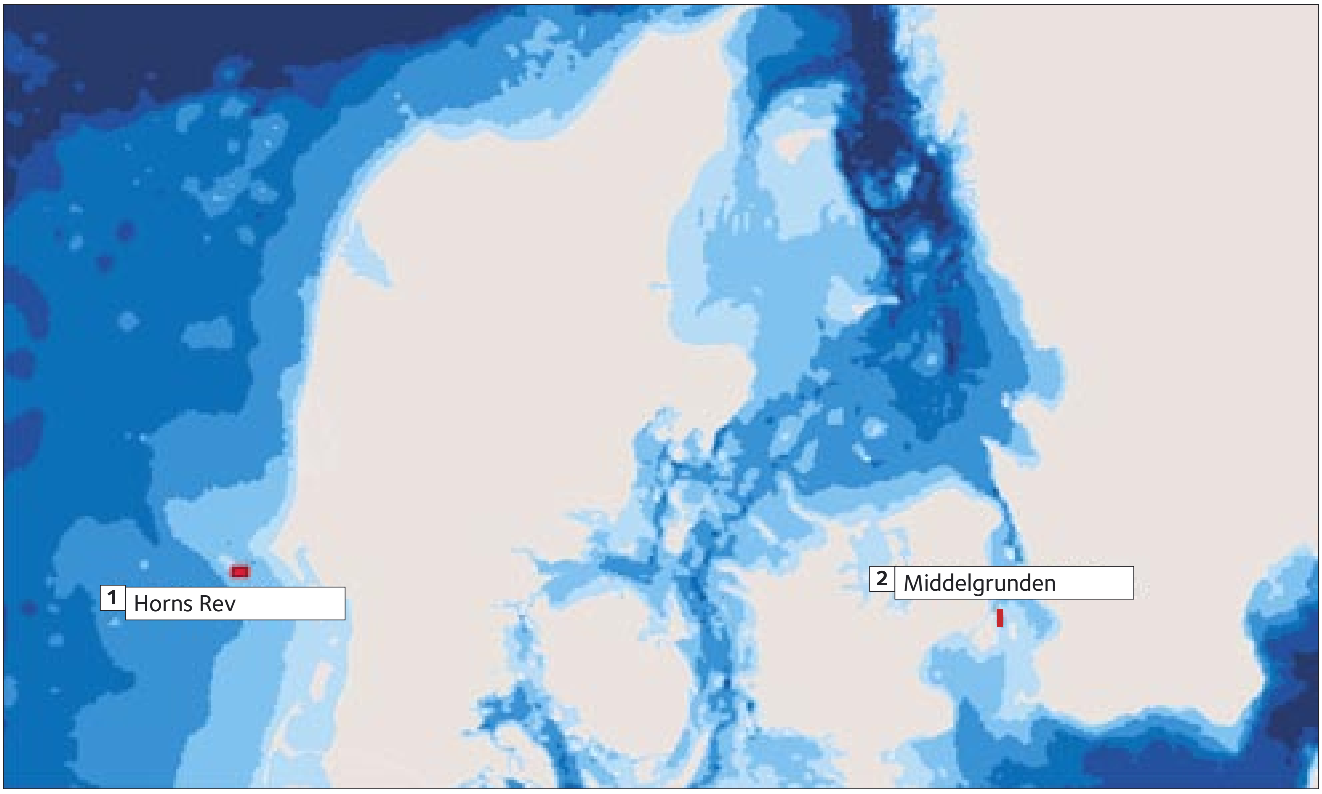
Figure 3.2 Commercial-scale offshore wind farms existing or under construction



Horns Rev wind farm

Middelgrunden wind farm

Figure 3.3 Horns Rev and Middelgrunden



All maps are purely indicative to show development scale. There is no suggestion that the resulting locations are where wind farms should, or could, be sited.

Figure 3.4 France

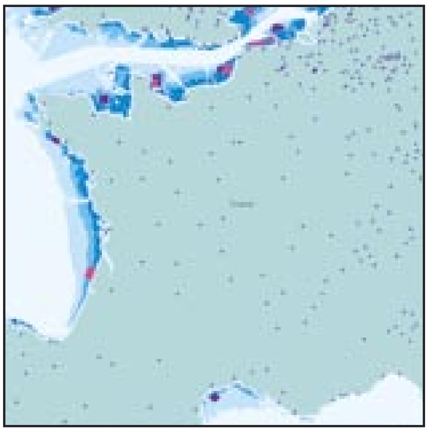


Figure 3.7 Ireland, the UK, Belgium and the Netherlands

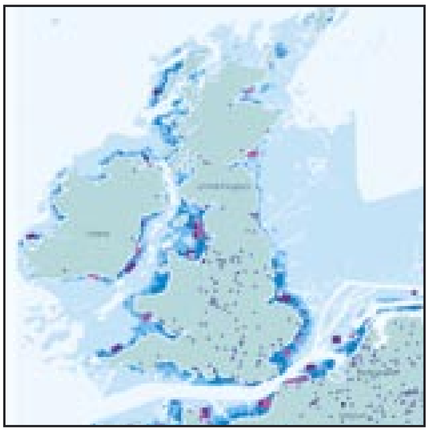


Figure 3.10 Sweden and Finland

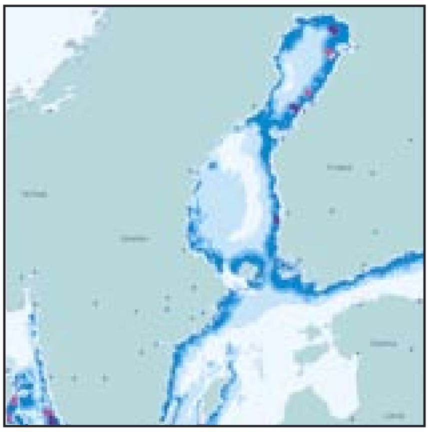


Figure 3.5 Germany and Denmark

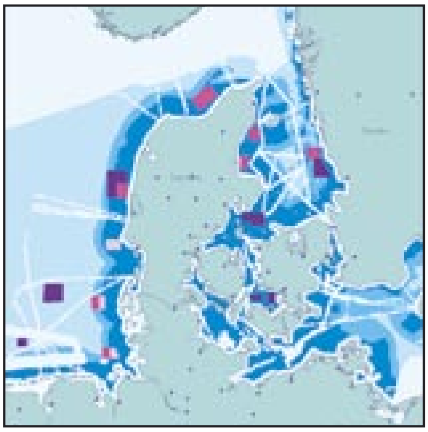


Figure 3.8 Italy

- Wind farms – scenario up to 2010
- Wind farms – scenario up to 2015
- Wind farms – scenario up to 2020
- Land
- Available area – scenario up to 2010
- Available area – scenario up to 2010
- Available area – scenario up to 2010
- Cities with more than 50,000 inhabitants

Figure 3.6 Greece

Figure 3.9 Spain and Portugal

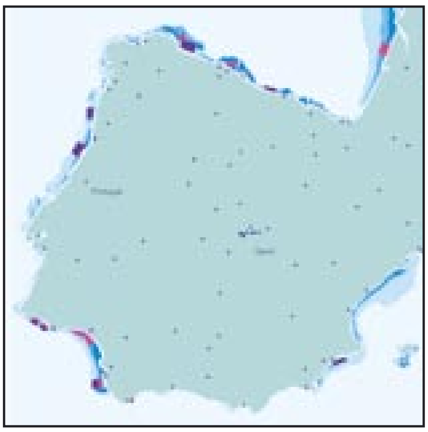
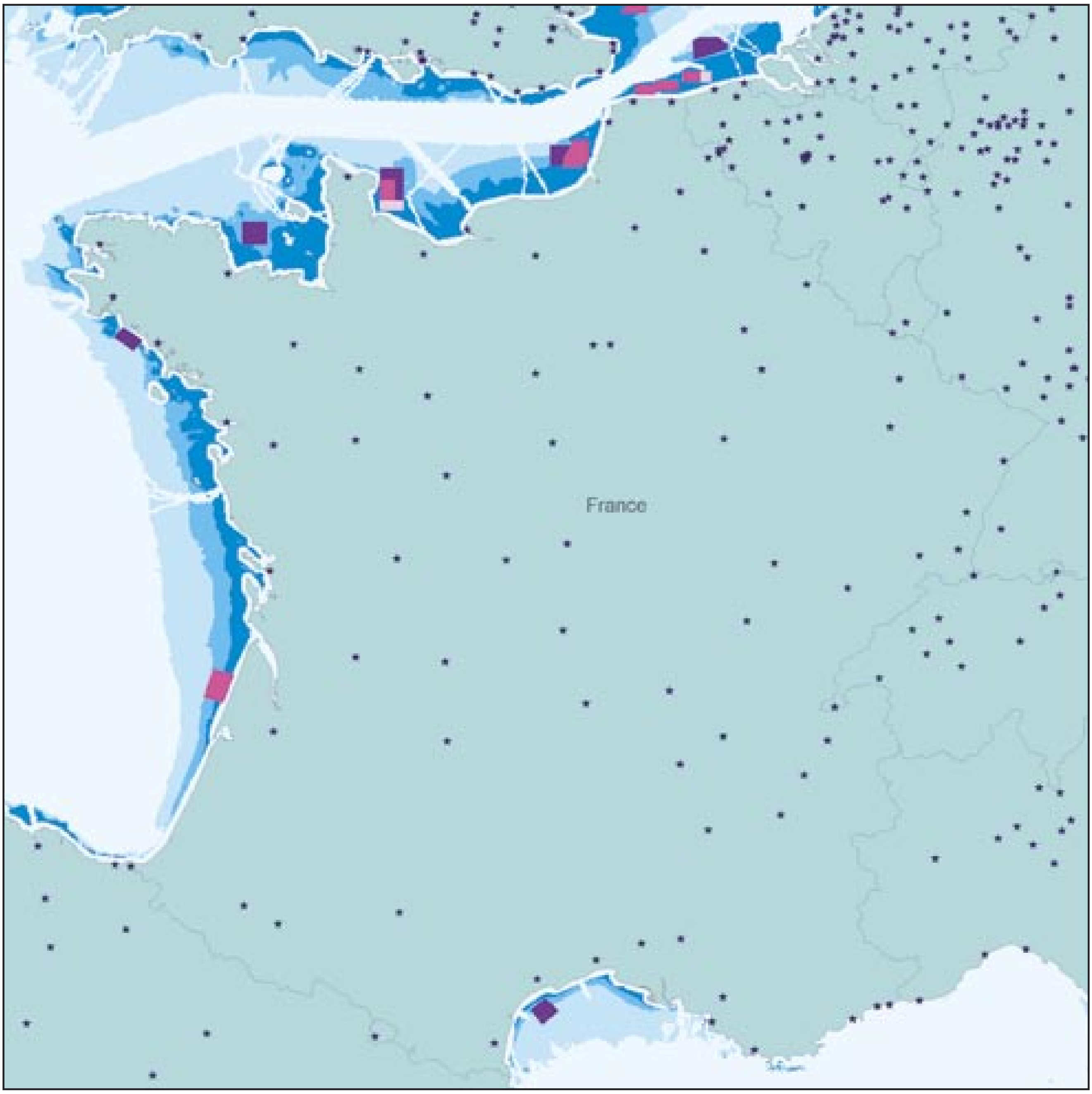


Figure 3.4 France



- Wind farms – scenario up to 2010
- Wind farms – scenario up to 2015
- Wind farms – scenario up to 2020
- Land
- Available area – scenario up to 2010
- Available area – scenario up to 2010
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- Cities with more than 50,000 inhabitants

Figure 3.5 Germany and Denmark

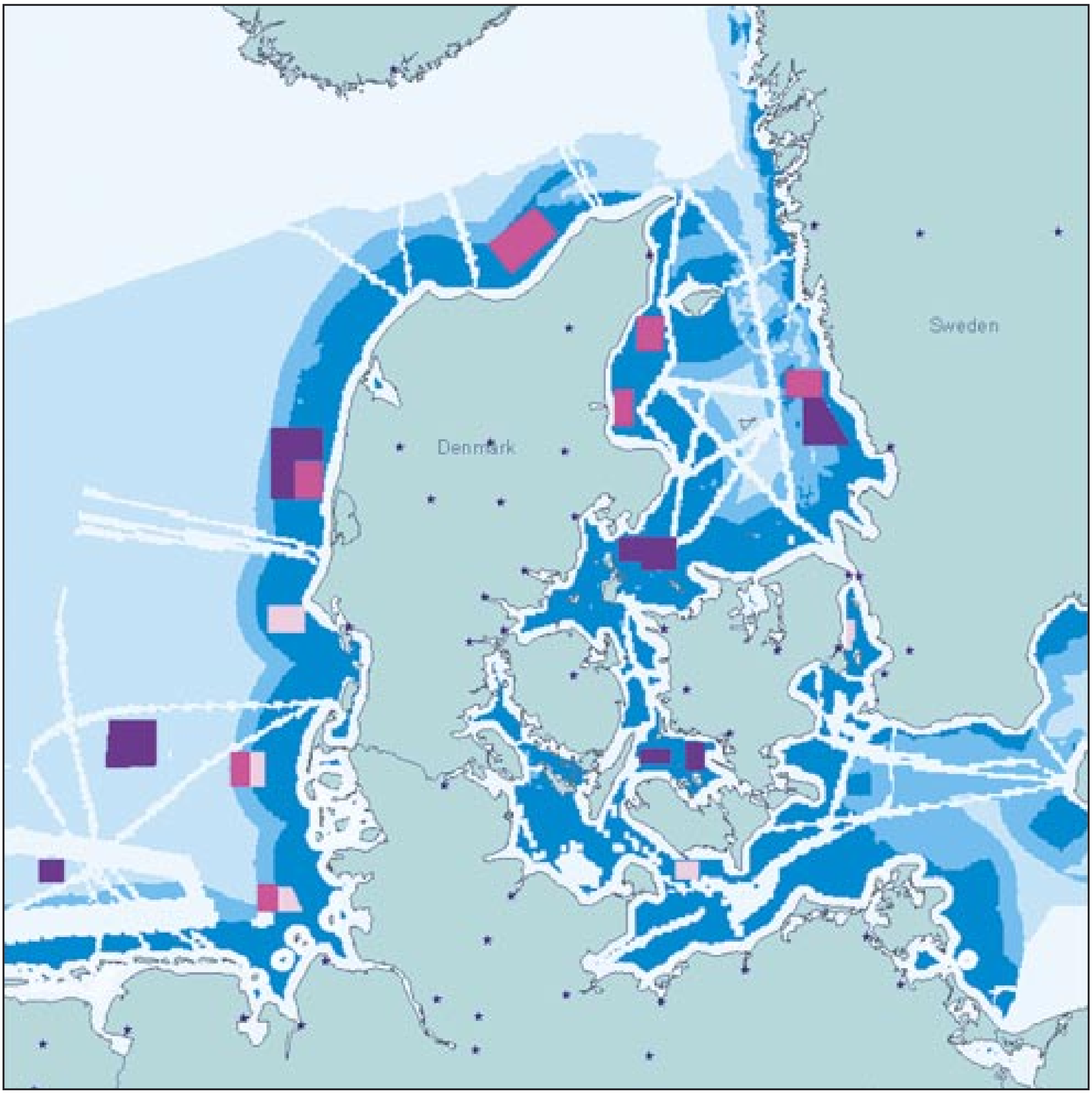

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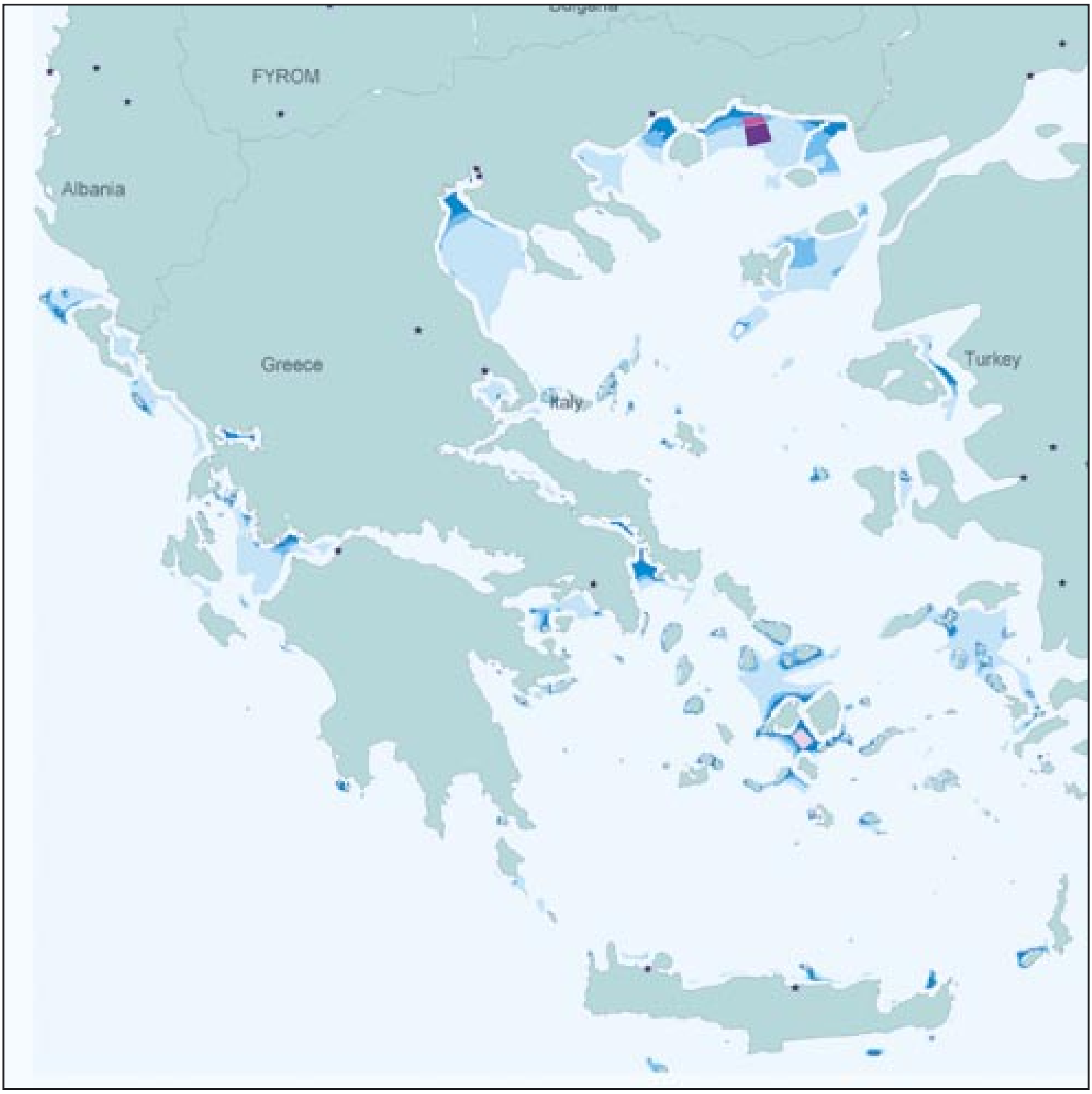
Figure 3.5 Germany and Denmark



- Wind farms – scenario up to 2010
- Wind farms – scenario up to 2015
- Wind farms – scenario up to 2020
- Land
- Available area – scenario up to 2010
- Available area – scenario up to 2010
- Available area – scenario up to 2010
- Cities with more than 50,000 inhabitants

Figure 3.7 Ireland, the UK, Belgium and the Netherlands

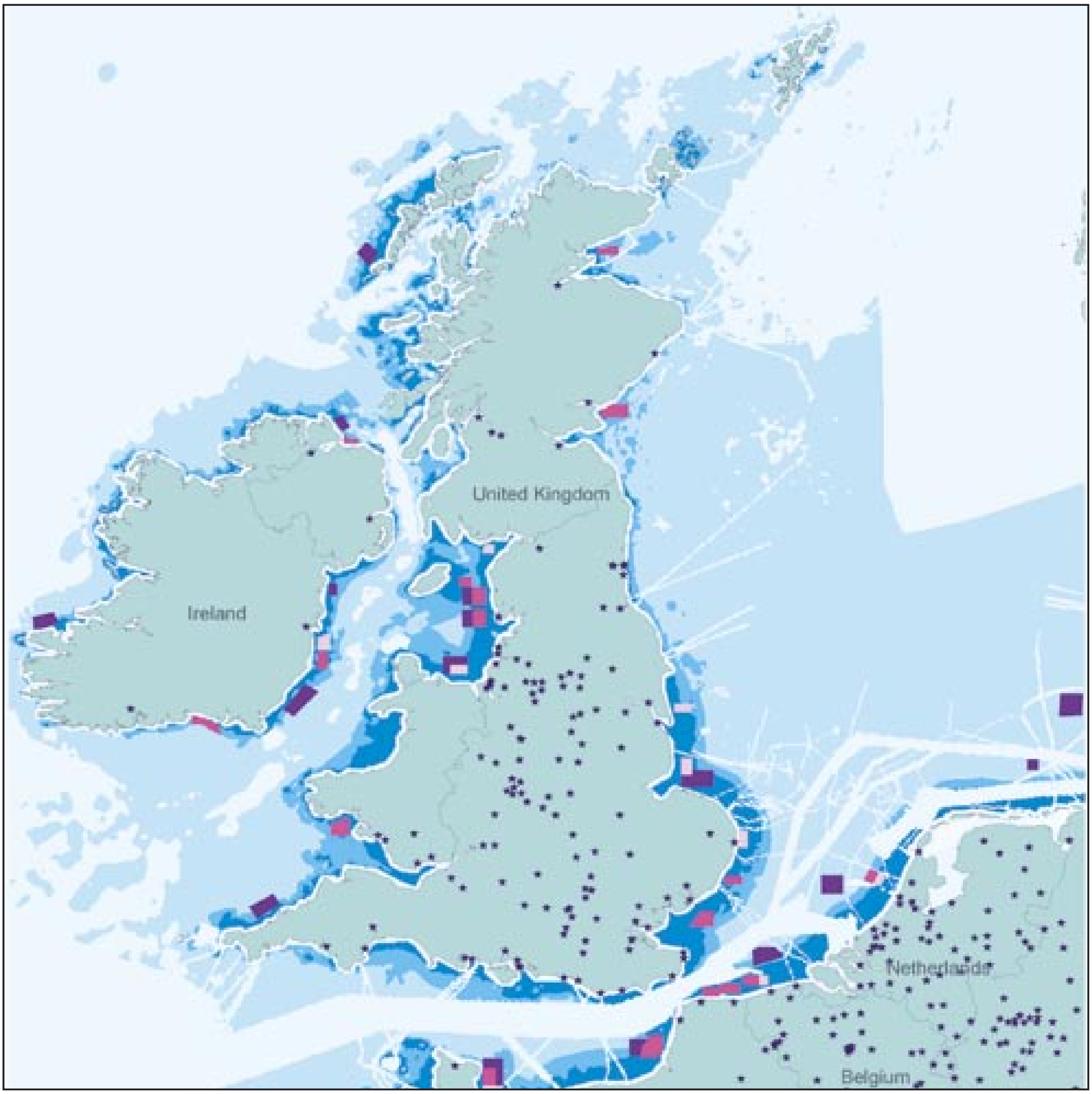


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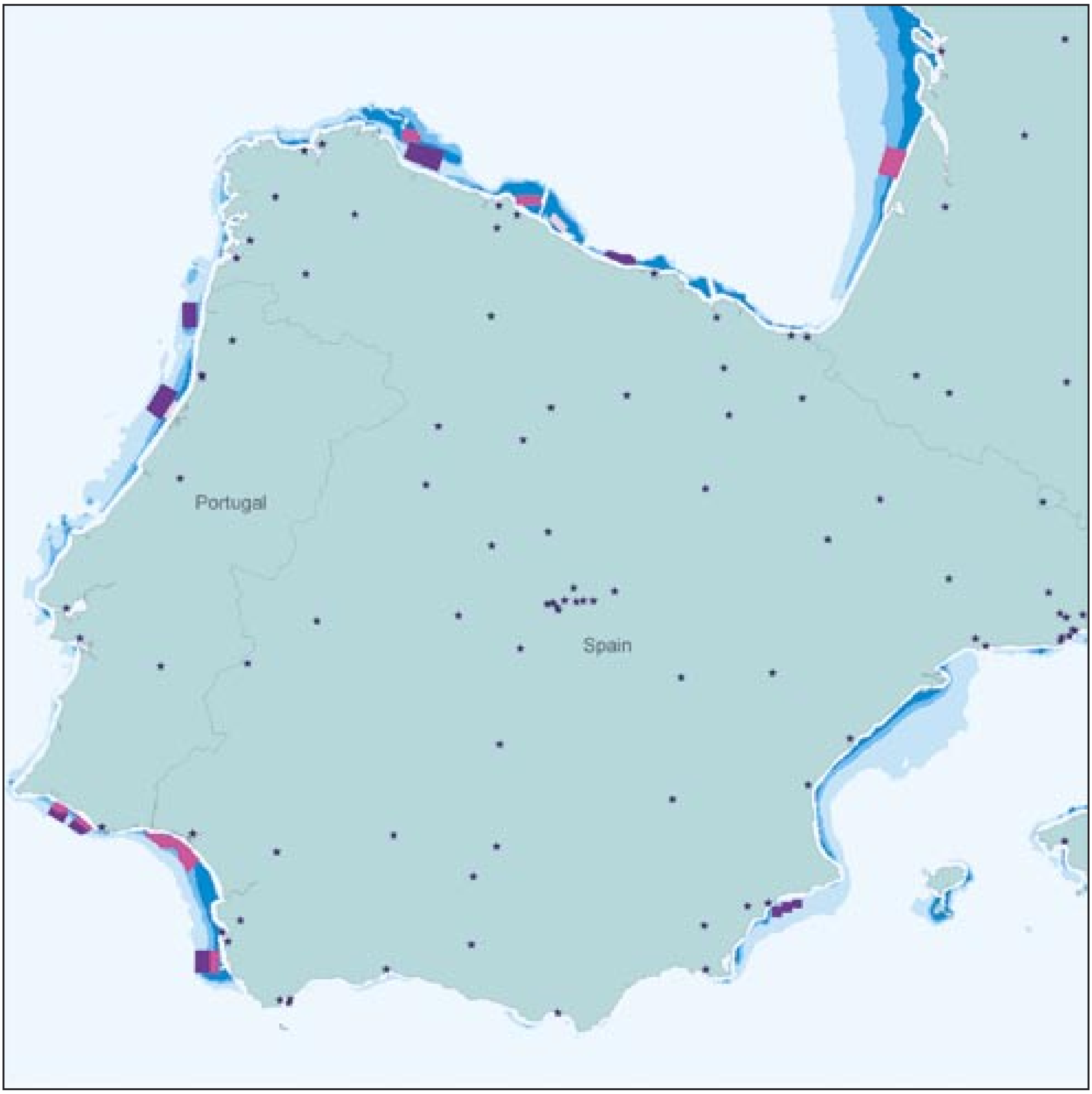
Figure 3.8 Italy

Wind farms – scenario up to 2010
Wind farms – scenario up to 2015
Wind farms – scenario up to 2020
Land
Available area – scenario up to 2010
Available area – scenario up to 2010
Available area – scenario up to 2010
Cities with more than 50,000 inhabitants

Figure 3.9 Spain and Portugal



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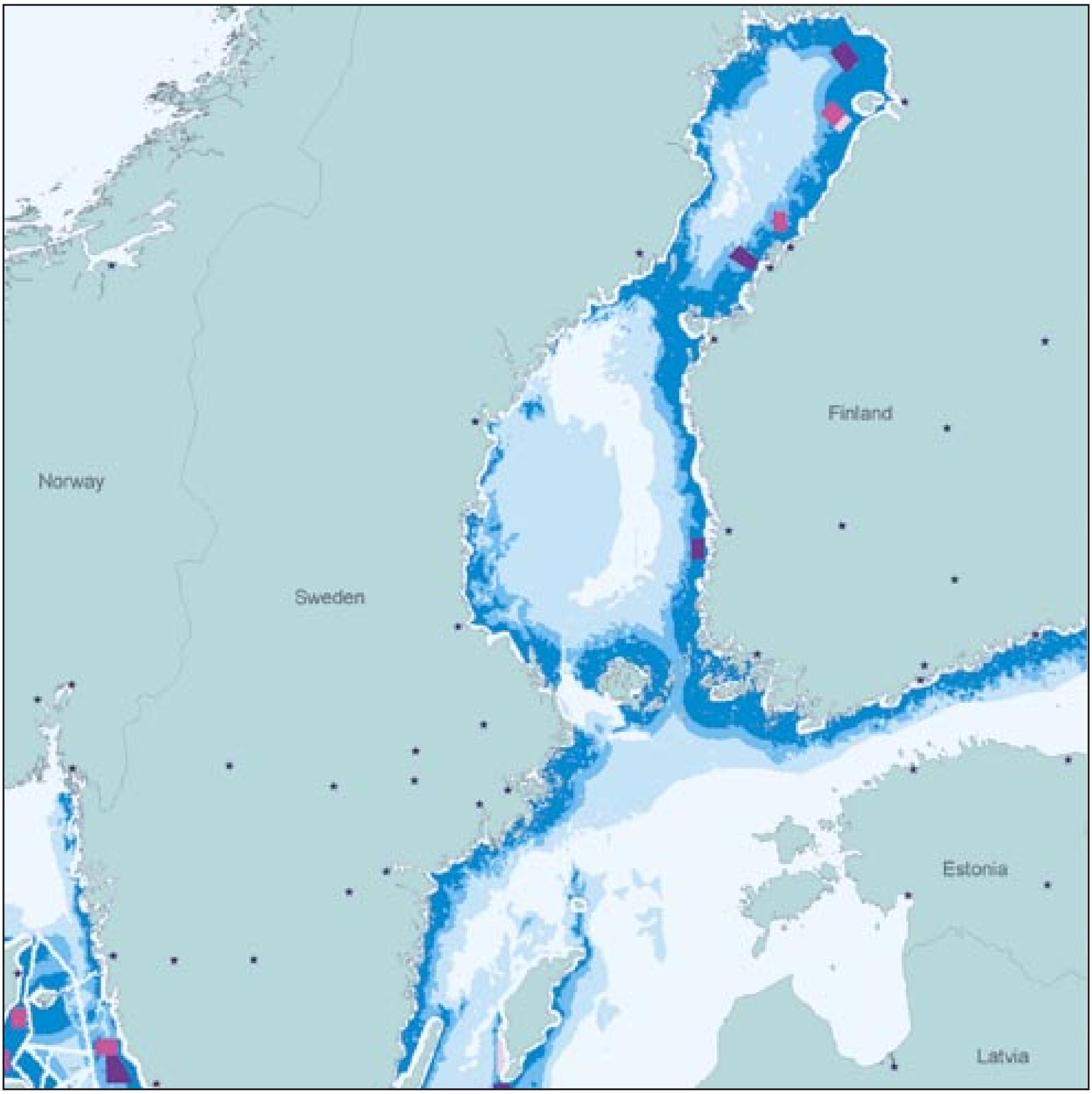


3.5 Capacity and annual energy yield

Tables 3.1 to 3.3 show the increases in offshore capacity and AEY to each scenario year. Table 3.4 shows the cumulative results for 2020. AEY values are derived from wind speeds modelled at 100m hub height. The capacity factor in all scenarios is approximately 35%. Each table also shows the area taken up by the wind farms placed in each scenario (including the space between turbines), and the percentage that this represents of the area available for development after constraints.

Table 3.1 2003 to 2010

	AEY (GWh)	Capacity (GW)	Area occupied (km2)	% of available area
Belgium	2,901	0.88	110	8.07
Denmark	12,978	3.86	483	1.97
Finland	1,087	1.05	131	0.50
France	6,063	1.84	230	1.44
Germany	8,007	2.30	288	2.98
Greece	1,141	0.92	115	4.35
Ireland	7,517	2.04	255	5.69
Italy	2,865	1.79	224	2.11
Netherlands	3,897	1.06	132	2.69
Portugal	2,043	0.82	102	15.36
Spain	3,805	1.35	169	2.40
Sweden	3,231	1.38	172	0.80
UK	26,711	7.86	983	2.95
Total	82,246	27.15	3,394	2.08

Table 3.2 2011 to 2015

	AEY (GWh)	Capacity (GW)	Area occupied (km2)	% of available area
Belgium	5,425	1.58	198	11.05
Denmark	39,795	11.54	1,443	4.40
Finland	5,412	4.26	533	1.39
France	46,911	15.12	1,890	6.36
Germany	9,911	2.84	355	2.12
Greece	412	0.66	82	1.38
Ireland	15,590	4.30	537	5.01
Italy	7,357	4.76	595	3.14
Netherlands	4,736	1.28	160	1.86
Portugal	6,315	1.94	242	8.71
Spain	36,378	11.31	1,414	11.19
Sweden	12,967	4.90	612	1.39
UK	67,856	19.48	2,435	3.45
Total	259,065	83.97	10,496	3.57

Table 3.3 2016 to 2020

	AEY (GWh)	Capacity (GW)	Area occupied (km2)	% of available area
Belgium	14,751	4.21	526	23.57
Denmark	42,353	12.38	1,548	1.77
Finland	11,866	8.09	1,011	1.60
France	53,091	15.82	1,977	3.02
Germany	22,848	6.40	800	3.03
Greece	1,203	1.73	216	1.00
Ireland	33,828	9.00	1,125	1.87
Italy	15,792	10.42	1,303	2.68
Netherlands	15,413	4.22	528	1.04
Portugal	30,830	9.98	1,248	12.60
Spain	37,648	12.86	1,607	4.82
Sweden	30,963	10.98	1,373	1.26
UK	68,999	19.41	2,426	0.82
Total	379,585	125.50	15,688	1.79

Table 3.4 Cumulative, 2020

	AEY (GWh)	Capacity (GW)	Area occupied (km2)	% of available area
Belgium	23,077	6.67	834	37.37
Denmark	95,126	27.79	3,474	3.98
Finland	18,366	13.40	1,675	2.66
France	106,065	32.78	4,097	6.27
Germany	40,766	11.54	1,443	5.47
Greece	2,755	3.30	413	1.91
Ireland	56,935	15.34	1,917	3.19
Italy	26,014	16.98	2,122	4.36
Netherlands	24,046	6.56	820	1.62
Portugal	39,188	12.74	1,592	16.07
Spain	77,831	25.52	3,190	9.57
Sweden	47,161	17.26	2,157	1.99
UK	163,566	46.75	5,844	1.97
Total	720,896	236.62	29,578	3.38

4. Finance

4.1 Experience

To date, the few existing commercial offshore wind projects have largely been developed on the balance sheet of the developers. As more and bigger offshore wind projects are developed, access to project finance will be essential in order to mobilise large-scale development. Without it, offshore wind will not emerge to fulfil its present potential.

It is partly because the financial risks, especially construction risk, are not yet properly understood by lenders that conventional project finance has not as yet been utilised for offshore wind. It is also because the market prospects for offshore wind, even in the short term, are very uncertain in most EU Member States.

Although risks are not yet quantified, it does not follow that offshore wind is likely to be a particularly risky business. Finance is readily available for offshore oil and gas production, for example, where risks certainly exist but where they are understood largely through experience. Also, there is a tremendous momentum associated with such a large, long-standing industry: lenders are not only familiar with the oil and gas sector, they are confident that there will always be a market for its products. Oil prices and predictions are a long-established, international benchmark for the economy as a whole.

So risk in itself is not the overriding impediment. Rather it is the relative novelty of the offshore wind industry, and the lack of established benchmarks against which risks can be quantified. The level of risk, even if it can be quantified, has implications for the cost of finance, and so it is generally desirable to reduce risk.

There are a number of ways in which risk can be quantified or otherwise addressed. Construction risk can be quantified through learning from real experience. Risk can also be offset through contractual allocation, as is common in a number of industrial sectors. This is where a contracting party explicitly accepts an identified risk, and its financial consequences, thus neutralising the financial consequences to the lender. It has knock-on implications for the make-up of the future industry, insofar as it implies the entry of some major conventional construction contractors credit-worthy enough to take on this kind of exposure.

Market uncertainty is largely in the hands of governments, at Member State and European level. Renewables markets are undergoing evolution, and there is a trend towards new liberalised market mechanisms such as tradeable certificates for renewable energy output or carbon content. Again, these markets are relatively new, and there are no long-standing price precedents or trends.

The early days of onshore wind were similarly characterised by a hesitance to lend to projects of which there was little previous experience. Many banks are now familiar with the onshore wind sector, and learning from experience was an essential part of attracting finance. So there are useful parallels to be drawn with the current offshore situation, although a major difference is the sheer scale of development for offshore wind energy. The huge size of many projects, and hence the amounts of money involved, make it all the more imperative that there should be keen interest among the banks in financing offshore wind.

Some banks are starting to show interest in providing finance for offshore projects, and it seems likely that some initial deals will be realised, at least in the case of those banks which have shown a willingness to provide funds to wind energy in the past. Initially the banks are likely to enter the offshore market by providing term loans for projects that have been completed. This would not however be enough to deliver *Sea Wind Europe*-scale development. Because of the probable need for syndicated and other forms of debt, which are employed for high-value finance deals, new banks, as yet unfamiliar with wind energy or offshore wind, will need to move into the sector.

So it is imperative that banks across the board be willing to lend to offshore wind projects, and there are important roles for policy-makers, the wind industry and the banks themselves in ensuring that this happens.

4.2 Levels of investment

Attracting finance to the offshore wind sector will need to overcome both perceived risk, and the requirement for much larger amounts of finance than has previously flowed to the onshore sector.

The largest offshore wind farm to have been constructed at the time of writing, comprising eighty 2MW turbines at Horns Rev in Denmark, had a project cost of some €270 million[16], or €1,687 per kW. Costs are expected to fall between now and 2020 (see Chapter 6), but at a very simplistic level the 240GW envisaged in *Sea Wind Europe*, at a capital cost of, say, €1,000–1,687 per kW spread over 17 years, represents an up-front capital investment of approximately €14–24 billion per year.

This figure compares to the IEA's 2002 *World Energy Outlook*[10] estimates of required new capacity of 658GW in the EU 15 between 2000 and 2030, at a total investment of $531 billion, or approximately €645 per kW. At a steady installation rate, this translates to just over €14 billion per year.

To judge from the per kW cost, the IEA appears to be assuming that all new capacity between now and 2030 will be provided by gas-fired generation. At present, wind energy is generally more capital-intensive than gas-fired generation, although it has zero fuel costs. This means that, per kW, it must find more up-front investment.

While perhaps comparable in money terms to investment in other sectors, €14–24 billion per year is a significant amount of capital investment, and especially so for a new industry. In onshore wind, banks have tended to contribute debt on a 'project' basis (that is the loan is secured at least partly against the project itself, as opposed to the assets of a corporation, for instance). Financed projects (in which commercial banks provided at least some of the debt) recorded by Thomson Financial, across Europe and across all sectors, cost a total of €37.6 billion in 2001 and €1,584 billion in 2002. The 2002 figures are heavily skewed by one gas field development project in Russia[17].

Given the difficulties in recording all deals and the relevant financial details, it is difficult to draw any firm conclusions. It is perhaps worth noting that some of the largest bank-financed projects listed by Thomson Financial were some form of government-backed public-private partnership or state privatisation, suggesting that public sector involvement in energy sector finance deals is not unusual.

Alternative means of raising finance are beginning to appear in the wind energy sector (see case study in Section 4.3). The emerging offshore sector is attracting many corporations with a wealth of experience in raising finance for multi-million euro projects. This collective experience can be expected to contribute to the development of finance models for offshore wind. Nevertheless, in terms of the appetite for strictly commercial financing of projects, there is a question mark over whether the levels required for 240GW of offshore wind by 2020 can be achieved. This would require banks to channel significant proportions of project funds to offshore wind. This in turn implies that for the benefits of a *Sea Wind Europe*-scale wind industry to be realised, there is a need to ensure that financial institutions are willing and able to make significant investments in offshore wind.

4.3 European banks

Previous sections have alluded to the central importance of early project demonstration, and of learning from the resulting experience. Institutions such as the European Investment Bank (EIB) and the European Bank for Reconstruction and Development (EBRD) play a very useful role in supporting such early development, but involvement in the renewables sector is variable and to date relatively minor.

In an evaluation of its energy-related investments, EIB acknowledges a low level of involvement in the renewables sector, and specifically in wind energy. Of all energy investments made by EIB between 1990 and 2000, less than 1% were in wind energy projects. EIB states that it has 'financed a very low share of the substantial increase in renewable energy investments during the second half of the 1990s, particularly wind energy'[18].

EBRD has recently initiated a strategic assessment of the potential for renewable energy for the countries in which it invests[19]. The ultimate aim is proactively to identify candidates for investment. In the first stage of the work, EBRD commissioned a series of renewable energy profiles for each of its Countries of Operation (COO). An anticipated second stage will focus on project-specific feasibility assessments. The draft terms of reference for this second stage state in their rationale that 'It is believed that EBRD can play a significant role in the development of the renewable energy market in the COO as it will be seen as an "honest broker" backing sound projects for the benefit of the COO.'

While EIB's acknowledgement of a lack of renewables investment and EBRD's recent assessments are good signs, there is clearly room for a wholesale shift in emphasis in these institutions towards renewable energy.

Case study
KfW Group

Many German wind farms benefit from loans channelled through the government-backed bank Kreditanstalt für Wiederaufbau (KfW). The KfW group is owned by the Federal Government (80%) and the regional governments or Länder (20%). It acts to promote German interests at home and abroad, and has a strong environmental agenda.

Case study
Evolution of wind farm finance

Onshore wind farm finance has traditionally been on a project-by-project basis, with limited recourse to anything but the project (meaning that liability for losses is limited to the assets of the project itself and does not extend to any other assets of the company). This has usually involved just one bank and, by finance standards, relatively small loans. However, as wind energy moves more into the mainstream, it is beginning to adopt the kind of financing arrangements required to raise significant funds.

In December 2002, German bank HVB announced a large loan to a wind power project, in the form of a syndicated package totalling €213 million. The credit facility, for Spanish developer Eurovento, is for six wind farms with a combined capacity of 201MW. Seven banks joined the over-subscribed syndicate with HVB and lead arranger Fortis.

More recently, the American electricity utility FPL completed the first ever wind energy bond deal, when in June 2003 it successfully sold bonds in New York worth $380 million for the finance of seven wind farms (totalling 680MW) in the USA.

4.4 Conclusions

Building confidence in offshore wind is the key to unlocking the large sums of money necessary for a thriving industry. Confidence will be nurtured first and foremost through experience of real projects, and through provision of a long-term, stable market environment for offshore wind. These are fundamental requirements, from which other necessary actions can be expected to flow.

Demonstration projects will need to span a range of environmental conditions, and hence there will be an ongoing need for demonstration, as there is in other industrial sectors, as the technology progresses and breaks new barriers. Governments, institutional banks and industry will all need to play a role: governments in ensuring that projects are given a consenting framework and grant support; institutional banks in provision of soft loans; and industry in proposing and delivering projects. Lessons learned should be widely disseminated throughout Europe.

Market provision is largely in the hands of governments, but they may look to industry players to detail, and justify, their needs in this respect.

Given these two building blocks – demonstration and market – work can usefully begin in a number of areas, including:

- Attracting commercial banks to the offshore wind sector. Banks have certain tests and procedures before funds can be released, and often there are dedicated teams specialising in financing a particular sector. Significant levels of lending to offshore wind therefore imply some institutional change and learning, which may be expected to occur over a period of six months to a year. This in turn suggests a need for timely action.

- Encouraging the development of finance structures: contract and project management structures can be expected to evolve to reflect the nature of the business offshore.

- Assisting successful financing of large-scale offshore wind projects by redirecting lending within EU Member States and EU-controlled financial institutions towards the renewables sector.

5. The technology

This chapter considers whether the technology can meet the challenge of large-scale offshore deployment. Each main component of a wind turbine is considered and analysed to determine whether a significant growth in demand is a reasonable expectation. Figure 5.1 illustrates these main components and their basic composition.

The scenario under consideration is the installation of some 240GW of offshore wind energy over 17 years, which translates to approximately 48,000 5MW machines, at an average rate of just under eight per day.

Figure 5.1
The main components of a wind turbine

Blades
Reinforced plastics

Nacelle
Glass-reinforced plastics (lower technology than the blades). Housing the generator, drive train, bearings, electrical controls and brakes

Tower
Steel

Foundation
Steel, concrete or mixture

5.1 Blades

The materials of which blades are made are predominantly composites, or reinforced plastics – essentially, fibres of a stiff material such as glass, carbon or wood, bound together by an epoxy or polyester resin. The composites used for wind turbine blades are very similar in make-up to those employed in the boat-building industry for hulls and masts, as well as in the aerospace industry for aeroplane nose-cones, nacelles and tail sections. As a group, composites are widely used in everyday manufactured goods.

Glass-reinforced plastic (GRP) has been the favoured material to date. Because of their high strength to mass ratio, carbon fibre spars (running through the central longitudinal axis of the blade) may become more common in larger offshore blades in the future.

The wind industry sources its blade materials from a specialist subsection of the composites market that supplies pre-pregs. These consist of preheated fibres encased in resin, rolled and stored in drums at a low temperature. The blade manufacturers then heat the pre-pregs for use in moulds, adding other constituents as appropriate. For the most part, pre-pregs come in standard forms, but latterly products have been specifically tailored to the wind industry, with a small number of companies specialising in supply to turbine manufacturers (see case study below).

Table 5.1 below details some approximate figures for the market volume suggested by an industry output of eight 5MW, 120m rotor diameter turbines per day[20]. It compares blades made wholly of GRP and blades with carbon-fibre-reinforced plastic (CFRP) spars.[21] Data for total (i.e. all industry sectors) world and US market volumes are provided for comparison in Table 5.2.

Table 5.1 Approximate materials volumes for blade construction

Note that any discrepancies in the annual totals are due to rounding error.

Constituent material	Mass of one blade (tonnes)		Per annum consumption (2,920 machines, 8,760 blades/ year) (tonnes)	
	All-GRP	CFRP spar, otherwise GRP	All-GRP	CFRP spar, otherwise GRP
Glass fabrics	15.91	4.36	139,394	38,150
Carbon fibre	0	2.85	0	24,966
Resin	7.84	4.05	68,657	35,434
Core	0.75	0.75	6,570	6,570
Miscellaneous	0.50	0.50	4,380	4,380
Total	25.00	12.51	219,000	109,500

Table 5.2 Composite world market data

Sources of figures: (1) Toray, the world's largest manufacturer of carbon fibre; (2) San Gobian Vetrotex, a glass manufacturer; (3) RAPRA, plastics and rubber specialists.

Material	Tonnes/year
Carbon fibre (from polyacrylanitrile precursor)	18,000 (1)
E glass for reinforcement	2,200,000 (2)
Epoxy resin (USA only, all applications)	275,000
Thermosetting resins (polyester and epoxy, all applications)	21,600,000 (3)

The current world production of glass fibre is large compared to the projected wind energy requirement. There may not be much spare capacity built in, but the large size of the industry means that extra capacity could be added relatively easily. Restricted supply of fabrics has been experienced by the blade industry in the past, but this has been addressed by longer-term purchasing arrangements.

The current world production of carbon fibre is dominated by Toray and Mitsubishi and is not large in relation to the projected wind energy requirement if carbon-based spars were to become the norm, which GH considers highly unlikely. The widespread application of carbon in blades worldwide would make wind energy the largest single market for the material.

Larger modern plants would allow extra capacity of several thousand tonnes per annum to be added, but this is not happening yet due to uncertainties over the rate of uptake of carbon for blade production. In practice, an addition in capacity of the order of 25,000 tonnes per annum could take five to ten years to achieve.

There is currently limited supply of the high-grade PAN (polyacrylanitrile) precursor fibre required for conventional carbon fibre manufacture. Another manufacturer, Zoltek, has developed a carbon fibre based on commercial-grade PAN, with mixed success.

An increase in supply to meet growing demand would be dependent on the lead times required for technical development, the re-equipment of blade production facilities for new moulds, possibly more demanding materials handling, and retraining of personnel. For these reasons, manufacturers may wish to extend the use of glass composites as far as possible by selective use of carbon, thereby avoiding a step change to CFRP-dominated construction.

The volumes of resin required in the projected scenarios are still relatively small quantities in relation to the world market for such materials. The base resins are shared by many applications, specific blends being created for structural use.

Plant for mixing formulated products and for making pre-pregs can readily be installed with capacities of tens of thousands of tonnes per annum and is therefore not expected to pose a limiting factor on future volumes. Either the all-GRP or the CFRP/GRP hybrid scenario would represent a huge growth potential for the current specialist intermediates (mixed resin and pre-preg) suppliers.

In Germany, work is under way into establishing methods of recycling glass fibre material used in wind turbines when they are decommissioned.

This short analysis suggests that, with the exception of carbon fibre, raw material supply should not be an issue. Specialist suppliers of pre-pregs to the industry will need to increase their capacity, and will need sufficient warning to enable them to do so.

Case study
Composites suppliers

Table 5.3 shows wind-related market volumes for two major pre-preg suppliers – SP Systems and Hexcel. It indicates the need to increase production in order to meet the 240 GW target[23].

Table 5.3 Wind-related turnover of pre-preg suppliers

(1)Converted from pounds sterling at a rate of €1.50 to ¢G1.
(2)Tonnage estimates based on £3.50/kg average price for glass fabric pre-preg.
Some carbon is already supplied, so total tonnage is probably less.

	€m(1)	Estimated tonnes
Hexcel	54	10,286
SP Systems	72	12,714

As discussed in the main text, suppliers are increasingly tailoring their products to this growth industry. SP Systems is a UK-based composites technology and manufacturing firm, supplying products to the wind energy, marine, transport and oil and gas sectors.
In 1999 it relocated and expanded its main manufacturing facility, in part to accommodate a purpose-built impregnation line capable of producing heavyweight materials required by its main wind energy and marine customers.
Hexcel is a multinational composites company with 11 manufacturing facilities in Europe and the USA, and a joint venture company in Japan. As well as the wind energy sector, it supplies products to the automotive, marine, aerospace, rail and sports goods industries.

Other players in the composites industry are already positioning themselves to supply a growing wind energy market. In May 2003, the magazine *Reinforced Plastics* brought out a wind energy special edition24 in which, for example, Dow Chemical states that in the context of a growth in wind energy its 'supply capabilities are global', and that 'as the industry's key players expand and invest in geographic markets outside their current participation ˘ [Dow Chemical] is in a position to supply.'

Case study
LM Glasfiber

LM Glasfiber is the world's leading blade manufacturer, making approximately 45% of the world's wind turbine blades. A Danish company, its origins go back to the (then) emerging fibreglass industry in the 1950s. At that time LM manufactured caravans and boats. Wind turbine blade production began in 1978, and today LM's principal output and core business is wind turbine blades. It has 11 production facilities across Denmark, Spain, India, China and the USA, and has some 3,300 skilled employees.

In 2001, the fund manager Doughty Hanson acquired LM Glasfiber for its private equity portfolio. Commenting on the deal, Doughty Hanson stated that it was 'delighted to acquire LM Glasfiber, which is a high-quality, successful business. We now intend to continue the international development of LM Glasfiber and thereby retain its market-leading positions in this fast-growing and internationally developing industry.' LM joins companies such as TAG Heuer (watch manufacturer) and Umbro (football-branded clothing) in Doughty Hanson's private equity portfolio.

5.2 Towers

Wind turbine towers consist of steel plate cut and rolled into a series of conical sections, which are then welded together into larger sections. In installation, tower sections are bolted to each other. Tower manufacturers purchase steel as hot-rolled plates, which they then cold-roll and weld using fairly standard machinery. The same manufacturers also tend to be producers of pressure vessels and oil tanks. An increase in demand for towers could easily be met by an expansion of facilities and the necessary equipment.

The production of 48,000 towers for 5MW machines would require approximately 12 million tonnes of steel (at 250 tonnes per 5MW turbine, including a steel monopile foundation), or an average of 0.7 million tonnes per year to meet the *Sea Wind Europe* target. This compares to annual EU 15 crude steel production of 158 million tonnes in 2001 and 2002 and 54.5 million tonnes in 2003[25]. EU production of rolled steel products in 2003 is forecast to have been 140 million tonnes[26], of which 9.4 million will have been hot-rolled plate.

The 2003 slump in crude steel production in the EU reflects overproduction in previous years, increasing imports and losses in the manufacturing sector. The European steel industry is very much in need of new markets.

Steel is a highly recyclable material. Approximately 47% of EU steel production is from recycled scrap.

Case study
Monsud

Monsud is a long-established Italian manufacturer of steel structures for large civil engineering projects. Wind energy projects now form a significant part of its business, along with other forms of renewable energy such as solar and geothermal. For the wind energy sector, Monsud provides tubular and lattice towers for wind turbines and electricity pylons. The company has two manufacturing facilities, one in Tufo, and the other in Avellino in southern Italy.

To date, Monsud has installed more than 1,000 towers (lattice and tubular) for Vestas and Bonus wind turbines.

5.3 Foundations

Two different foundation types have been utilised for existing offshore wind farms – the monopile and the gravity-based foundation. Further options exist, including a tripod structure which is proposed for the Borkum West project in Germany.

Monopiles are effectively an extension of the steel tower, driven or grouted into the seabed. They are also used extensively in the off- and nearshore environment for supporting oil and gas platforms, jetties and other coastal structures.

Manufacture is similar in process to that of steel towers, but at present there are very few facilities equipped to roll the large-diameter, thick steel tubes required for foundations.

Several manufacturers have foreseen this gap in the market, and have plans under way to establish the necessary capability. For example, Sif Group has plans to quadruple its capacity to manufacture monopiles, and there has been entry of new monopile manufacturers in Scotland. Sea access (for raw material import and product export) and space are key requirements for monopile manufacture, which tends to favour old shipyards and coastal oil and gas facilities.

Case study
Sif Group

Based in the Netherlands, Sif Group specialises in the production of thick-wall steel tubular structures. Traditionally, its markets have been in offshore oil and gas (large piles and jackets), pressure vessels and other civil construction projects. Latterly, it has found a growing market in the manufacture of offshore wind monopile foundations, and has established a dedicated production line.

Figure 5.2 shows a monopile from the Sif production line, and Figure 5.3 Sif's shipyard on the river Maas.

Figure 5.2 Wind turbine monopile foundation at Sif factory

Figure 5.3 Sif shipyard

Gravity-based foundations: there are a number of options for gravity foundations, which can be either blocks or caissons of, typically, steel and/or concrete, with the caisson types ballasted with water, iron or grout. Gravity foundations are also used in the offshore oil and gas industry for supporting platforms. Those involved in the manufacture of gravity foundations have tended to be large civil construction companies. Like monopile manufacture, fabrication requires facilities with sea access and space. Temporary yards can also be set up to construct foundations close to site.

Case study
Gravity foundations, Middelgrunden

The Middelgrunden offshore wind farm employs gravity-based concrete and steel composite foundations – a steel inner encased in reinforced concrete – designed by engineers Carl Bro. Construction and transportation were undertaken by a syndicate of two construction companies, Monberg & Thorsen and Phil & Son. Manufacture took place in a nearby dry dock at the old Burmeister & Wain shipyard (shown in Figure 5.4), brought back into operation by the syndicate after eight years of inactivity[27].

Figure 5.4 Foundation manufacture at Burmeister & Wain shipyard dry dock

Figure 5.5 Installation of HornsRev transformer

Other structures: a number of other foundation designs have been proposed, mostly (although not exclusively) drawing on designs already in use in other offshore sectors. These typically make use of piling, gravity or a combination of the two in the foundation, but elaborate on the total support structure to provide stability for larger machines and deeper locations.

Thus the **tripod** supports a central tube which extends into the tower, with each corner of the tripod support piled into the seabed. A **jacket** can be any of a variety of arrangements whereby a central tube is surrounded by numerous piled supports.

Suction-based foundations have also been proposed, replacing the pile. At each point at which seabed penetration is required, an inverted 'bucket' forms the foundation. Suction is applied until it penetrates to the desired depth.

There is also a potentially distinct and significant market for the provision of substation support structures, which are likely to be similar in design to those used for oil and gas minimum facility platforms. Figure 5.5 shows the installation of the first ever offshore grid transformer, at Horns Rev.

The design of new support structures for offshore wind turbines is likely to continue and evolve over the next decade. In contrast to onshore, where turbines are classified according to their ability to withstand a range of wind speeds, offshore is a more complicated environment which combines wind, wave, ice and sea current loads. Ironically, the wind is less turbulent offshore and hence, in some senses, is more benign. Foundations and support structures are likely to be much more specific to each site, which in turn provides an opening for new applications of conventional civil engineering concepts.

Case study
Corus

The British steel company Corus is currently examining the application of its bi-steel product in support structures for offshore wind turbines. Bi-steel has been developed for its high strength and modularity and has applications across defence, offshore and other sectors. Each panel comprises a pair of steel plates connected by transverse steel bars. Strength can be increased by filling the gap with concrete or other materials.

5.4 Nacelle

The nacelle provides an enclosure for the drive train and various electrical and other components, including the generator itself.

With the exception of some direct-drive machines (see below) the **generator** in a wind turbine is close in function and design to a conventional electrical machine. An electrical machine is manufactured from electrical steel, copper and insulation materials. Each wind turbine also has a transformer of the same concept as those used throughout the electrical industry.

The **gearbox** in the nacelle is designed specially for the wind industry, and consists of steel casing, bearings, gears and shafts. Current wind turbine gearbox manufacturers have all diversified from mainstream gearbox manufacture, some having separated off dedicated wind industry supplier companies. For example, the largest supplier to the European market, Winergy (formerly Flender), was separated and floated from its parent Deutsche Babcock. It now supplies exclusively to the wind energy sector.

Other major gearbox suppliers to the wind industry include Hansen, part of the UK Invensys group, Metso, a Finnish gearbox manufacturer, Lohman & Stolterfoht in Germany, Eickhoff in the US and Fellar in Spain.

A relatively new generation of direct-drive machines avoids the need for a gearbox. An option for these direct-drive machines is to utilise permanent magnet generators. This requires a supply of ferrite or rare earth magnets. Ferrite is readily available, but rare earth elements less so, although there are substantial supplies potentially available in China.

Modern offshore nacelles also now include handling equipment such as cranes, and extra access provision for boats and helicopters, which aim to maximise access and maintenance options. Figure 5.6 shows personnel being transferred to a turbine at Horns Rev. For some applications, nacelles are now being designed with their own helideck.

Figure 5.6 Helicopter access

Case study
FKI nacelle facility, Loughborough, UK

FKI is a UK-based international engineering group, active in manufacturing, including of generators. Last year, FKI purchased the German wind turbine manufacturer DeWind, and has recently announced the establishment of nacelle production at an FKI facility in Loughborough. The operation will provide an increasing number of jobs over the next two years, and in its first year will have the capacity to produce over 130 wind turbines of up to 2MW power rating.

The acquisition also shows how the wind industry is offering diversification opportunities for sectors that are suffering from a downturn in orders. DeWind offered a good fit for FKI – DeWind had no in-house manufacturing capability, while FKI, suffering from a drop in the mechanical engineering sector, had spare manufacturing capacity.

In the long term the DeWind factory is likely to work closely with adjacent FKI company facilities such as the generator manufacturer Brush and Hawker Siddeley, both well-known names in the power industry.

5.5 Installation vessels

As recently as 2002, many commentators were voicing concerns about the availability of specialised cranes acting as a limitation on the installation rate of offshore wind farms. However, following a good response from existing offshore contractors and some new market entries, it is clear that industry will respond well to any increase in demand, given a positive market environment. Installation vessels used for oil and gas or other purposes have been converted for use in offshore wind farms, while two companies (Mayflower Energy and Mammoet Van Oord) have invested in purpose-built vessels.

Cable laying can be carried out from a range of existing vessels already used for this type of work and fully fitted with appropriate equipment, including cable carousels, remotely operated vehicles and trenching/jetting equipment.

Case study:
converted vessels A2SEA

The company A2SEA has installed turbines for both the Horns Rev (80 machines) and Nysted (72 machines) projects. It has patented a design which is effectively a converted carrier vessel, based on a widely used standard design, but with four legs underneath and several cranes on top. Its standard design means that there is an inbuilt flexibility to respond to increasing demand. Figure 5.7 shows an A2SEA vessel at the Nysted project.

Case study:
purpose-built Mammoet Van Oord

Mammoet Van Oord is a relatively young (2002) company, formed in response to the requirements of offshore wind farm and other marine installations. It is a joint venture between Mammoet, a world-wide heavy lifting and transport specialist, with commissions including salvage of the Kursk nuclear

Figure 5.7 One of the A2SEA vessels at Nysted

Photograph courtesy of Gunnar Britse

submarine, and Van Oord ACZ, an offshore sector construction and installation contractor. Other shareholders are Hovago Cranes (part of the Baris Group) and Marine Construct. The new company operates the purpose-built Jumping Jack (shown in Figure 5.8), a jack-up barge with an onboard crane, which was used to install the Horns Rev foundations.

Figure 5.8 Jumping Jack

Case study:
purpose-built Mayflower Energy

The Mayflower Resolution will be the first offshore wind installation vessel to be built by the UK company Mayflower Energy. Purpose-built, it is the direct result of entrepreneurial exploitation of an identified new market. The Resolution has been designed to install up to 10 turbines in one visit to the offshore location and to operate with no need for any supporting vessels. It can also be used in deploying foundations and cable laying.

5.6 Future development

There is a limit to the feasibility and cost-effectiveness of placing structures on and in the sea bed as depth increases. For offshore oil and gas, this depth depends in part on the costs justified by the potential reserves. It then becomes necessary to consider floating structures: deep-water oil and gas platforms can be thought of as stationary boats with sophisticated moorings.

Several studies have investigated the concept of floating offshore wind turbines. Proposals for the floating base(s) differ from those of current offshore platforms, reflecting the multiple structures and very different loads experienced. Proposed mooring arrangements are drawn from existing practice.

GH has previously concluded that the concept of floating offshore wind farms is technically feasible, but that the mooring systems render it uneconomic at present. It nevertheless remains a possibility in some areas, with known investigations ongoing for applications in at least two European countries and Japan.

The use of new installation methods is also under investigation, including the concept of 'self-installation' (methods that avoid the need for a large offshore crane barge) and other approaches that minimise assembly in the offshore environment. The main aim is to reduce installation time.

5.7 Conclusions

For the most part, the construction and installation of offshore wind turbines employ generally available materials and skills. It is the adaptation of these to the offshore wind sector that is often the innovative factor. There are many examples of companies making this adaptation, and in so doing finding a growing market for their products. Also, because other markets for traditional occupations in heavy engineering are declining, wind energy can offer a reversal of declining employment trends.

The main raw material constituents for turbines – steel, composites and concrete – should not pose any limitations on large-scale deployment of offshore wind. Not surprisingly though, industry capacity to supply relevant precursors for composites, and to produce the final manufactured products, will need to gear up. Again, this will include the utilisation of disused and declining facilities belonging to the heavy engineering and other conventional sectors.

Niche market materials – carbon fibre and rare earth metals for magnets – are not widely utilised at present, and wholesale adoption in offshore wind would represent their single largest market.

In the medium to long term, and especially as turbines move into more hostile environments, there will be some technological challenges. These will include support structure design and access solutions. Experience in traditional civil engineering and marine industries is already being utilised in this respect.

Industry has already proved its willingness and ability to respond to an increase in market demand, perhaps most obviously in the installation sector where new and converted vessels have emerged to meet demand. Increasingly, companies not previously associated with wind energy are becoming aware of the potential for their business, and are positioning themselves to respond to market opportunities.

These observations and conclusions on technology show that all the elements are in place for a thriving environment in which offshore wind becomes a mainstay of Europe's industrial and technological sectors. Danish companies in particular have a significant market share, which demonstrates the benefits to be gained from early market support. Europe as a whole is well positioned to capture a significant share of the global offshore wind sector, but again (and this holds true for all aspects of the business) a long-term, stable market is the most effective means of encouraging companies to invest.

There are also implied roles for development agencies and governments in targeting industrial and R&D support to the offshore wind sector. In order to capture economic benefits, significant growth in offshore wind needs to be underpinned by a determination to retain manufacturing facilities and know-how within Europe. Where facilities have been converted, or where there is experimentation with new ideas, support has invariably been channelled through inward investment, R&D or economic development policies.

6. Costs

A selection of comparative cost assessments is presented here to give an indication of the numbers which influence current decision-making.

6.1 Generation costs

Generation costs are often quoted as either a cost per kWh or a capital cost per kW. The former requires assumptions as to both the initial capital cost and annual operation and maintenance (O&M) and fuel costs, with discount rates applied over the lifetime of the project. The latter does not include any ongoing annual costs.

A thorough comparison of unit energy generation costs, with an explanation of their derivation, is presented in a 2002 UK Government Cabinet Office report, *The Energy Review*[28]. These figures are reproduced in Table 6.1. The report was compiled by a panel of government-appointed experts to inform a (then) imminent energy White Paper.

In its White Paper, the UK Government went on to prioritise the environment in setting goals for the energy sector. It set out a strong commitment to the long-term future of renewables and energy efficiency, in the context of wider benefits for the economy. On renewable energy, the White Paper concluded that 'technologies such as onshore and offshore wind and biomass are potentially – after energy efficiency and alongside Combined Heat and Power (CHP) – the most cost-effective ways of limiting carbon emissions in the longer term.'[30]

Table 6.2 opposite shows present-day IEA capital expenditure estimates for a range of technologies, as published in 2003[31].

Both sets of cost estimates shown are based on conventional economics. It can be seen then that, **even before externalities** and (in the case of the IEA estimates) fuel and operating costs, offshore wind power is comparable in cost to new coal plant and nuclear electricity generation.

The inclusion of a confidence level in cost estimates for *The Energy Review* is a factor which is not often explicitly stated, but is very important for decision-making. It is effectively stating that for those technologies of which we are confident and have extensive experience, costs are demonstrably achievable.

Table 6.1 UK Performance and Innovation Unit cost estimates

Technology	2020 unit cost, 5–15% discount rate		Confidence in estimate
	Pence/ kWh	[29] €cents/ kWh	
End use efficiency	Low	Low	High
Photovoltaic	10–16	15–24	High
Wind – onshore	1.5–2.5	2.3–3.8	High
Wind – offshore	2–3	3–4.5	Moderate
Energy crops	2.5–4	3.8–6	Moderate
Wave	3–6	4.5–9	Low
Fossil with CO2 capture and sequestration	3–4.5	4.5–6.8	Moderate
Nuclear	3–4	4.5–6	Moderate
CCGT	2–2.3	3–3.5	High
Coal gasification (IGCC)	3–3.5	4.5–5.3	Moderate

Table 6.2 IEA World Energy Investment Outlook cost estimates
Note: Centralised generation is large-scale and transmission-connected.
Distributed is smaller-scale and distribution-connected.

Technology	Capital expenditure	
	$/kW	[32]€/kW
Gas combined cycle	400–600	320–480
Coal – conventional	800–1,300	640–1,040
Coal – advanced	1,100–1,300	880–1,040
Coal gasification (IGCC)	1,300–1,600	1,040–1,280
Nuclear	1,700–2,150	1,360–1,720
Gas turbine – central	350–450	280–360
Gas turbine – distributed	700–800	560–640
Diesel engine – distributed	400–500	320–400
Fuel cell – distributed	3,000–4,000	2,400–3,200
Wind – onshore	900–1,100	720–880
Wind – offshore	1,500–1,600	1,200–1,280
Photovoltaic – distributed	6,000–7,000	4,800–5,600
Photovoltaic – central	4,000–5,000	3,200–4,000
Bioenergy	1,500–2,500	1,200–2,000
Geothermal	1,800–2,600	1,440–2,080

Renewables are coming of age in a time of unprecedented economic scrutiny and competition. Onshore wind power has a proven track record of cost reductions: in the UK for instance, onshore wind minimum bid prices for the Government's competitive support mechanism in England and Wales (the Non Fossil Fuel Obligation), dropped from 4.56p/kWh in 1994 to 2.43p/kWh in 1998. The dramatic cost reductions achieved in onshore wind are largely the result of a design ethos which has responded to cost pressures, and the opportunity to achieve economies of scale. Offshore wind is similarly expected to achieve cost reductions, given the appropriate opportunities.

6.2 Externalities

It is important to understand that simply continuing with the present electricity system will not result in falling or steady costs. In addition to environmental loss, environmental economists argue that a 'business as usual' approach could well result in higher total costs to society, compared to more sustainable alternatives. There are many reasons for this, including:

- the ongoing need to replace and expand the conventional electricity supply system;
- the growing insecurity of oil and gas supplies;
- the burgeoning costs of coping with environmental degradation;
- costs associated with a decline in human health;
- costs associated with relying on energy supplies from non-domestic sources (sometimes referred to in terms of security of supply);

- indirect costs such as subsidies, tax relief, R&D, policing and regulation, which are often not considered in quoted costs; and

- the cost of carbon – including policy measures such as a carbon tax, litigation costs and insurance premiums.

With the exception of the first two, these additional costs are termed 'externalities' and represent costs borne by society that do not form part of a conventional comparison between technologies. There have been a number of attempts to quantify energy-related externalities, one of the best-known of which is the EC-funded ExternE project. The product of collaborative work between EU and US researchers, it attempts to translate into monetary terms the life-cycle impacts of a variety of technologies.

ExternE results for the electricity sector in the EU 15 (excluding Luxembourg) plus Norway are summarised in Table 6.3, the range of values representing the lowest and highest country-specific results. The spread of values for each technology reflects differences in national circumstances and in the evaluation of externalities by each participating country[33].

The context in which the ExternE results were generated is crucially important to understanding them – they take an academic approach to quantifying externalities which are not otherwise reflected in conventional pricing. For the most part they also only consider environmental effects, and do not include security of supply, public liability in the event of major accidents, or so-called 'legacy' costs such as the treatment and storage of existing stockpiles of nuclear waste. There are also very wide-ranging and different types of uncertainty attached to each stage in the derivation of the final figures.

There has been some debate over the external costs of nuclear power, with environmental groups arguing that it is a mistake not to include its legacy costs, or to assume that current decommissioning funds will prove to be sufficient.

The main conclusion is that renewables in general, and wind in particular, have negligible environmental externalities, whereas fossil fuels incur additional environmental costs. This demonstrates empirically that wind energy would be one of the cheapest forms of electricity generation if environmental externalities were internalised. While the study examined onshore wind, the net externalities of offshore wind are thought to be of a similar order of magnitude[34].

Table 6.3 Summarised ExternE results

Technology	External cost range (€cents/kWh)
Coal/lignite	1.8–15.0
Oil	2.6–10.9
Gas	0.5–3.5
Nuclear	0.24–0.74
Biomass	0.1–5.2
Hydro	0.004–0.7
Onshore wind	0.05–0.26

A key recommendation from ExternE was the recognition of external costs through either taxation or specific subsidy. This would reflect either the cost (taxation) or avoided cost (subsidy) of different types of energy generation.

Development of the ExternE method continues.

6.3 Outlook on costs

The European Green Paper *Towards a European Strategy for the Security of Energy Supply*[35] states that 'we have to be aware that some renewables need significant investment, as was the case for that matter with other energy sources, such as coal, oil and nuclear energy.'

The UK's *Energy Review*[28] notes that 'support for renewables will induce innovation and "learning", bringing down the longer-term unit costs of the various technologies as volumes increase and experience is gained. In this way, today's investment buys the option of a much cheaper technology tomorrow.' The follow-on White Paper[30] states that 'specific measures are needed to stimulate the growth in renewable energy that will allow it to achieve the economies of scale and maturity that will significantly reduce its costs.' These statements show an acknowledgement that costs will be incurred in a move to renewables, and at the same time awareness that this should be seen in its full context.

The policy response to these issues has been to introduce a variety of EU Member State and EC-level measures in support of renewable energies, including offshore wind. These include targeted market support mechanisms such as feed-in tariffs and tradeable green certificates implemented by Member States; and within the EU the Renewables Directive and, latterly, a proposed carbon trading regime.

A proposed Directive for an EU carbon trading regime has had its first reading in the European Parliament, and the Council of Europe adopted a common position on the proposal in December 2002. The basic concept of the proposal is to allocate emission allowances against groups of greenhouse gas emitters, including thermal electricity generators, and require the subsequent submission of an allowance against any emissions. Because the total emission allowances will be capped in some way, a market for allowances will be created between companies, with those with lower abatement costs selling emissions to those with higher abatement costs.

The estimated price at which allowances will trade varies over quite a large range depending on the commentator. Until all Member States confirm their National Allocation Plans and until ancillary measures such as the Linking Directive are finalised the actual price of traded carbon is impossible to predict accurately. The EC itself refers to estimates of €26 or less than €13 per tonne of CO_2, depending on the effect of the Linking Directive and the limit (if any) put on the crediting in the EU trading scheme of carbon allowances that come from projects developed outside the EU[36]. By contrast, the UK regulator Ofgem refers to a much higher price estimate of as much as €49 per tonne of CO_2.

Case study
Impact of emissions trading on UK electricity generation costs

The UK electricity regulator, Ofgem, estimated the impact of the European Emissions Trading Scheme on the UK electricity market based on one of the available estimates of prices at which carbon allowances will trade. Ofgem reported this at €33 to €49 per tonne of CO_2. It found the implications for UK generators were an increase in cost of £19.40 to £28.80 per MWh (€29.10 to €43.20 per MWh) for coal-fired generation and £8.10 to £12.00 per MWh (€12.15 to €18.00 per MWh) for gas-fired generation[37]. If realised, these additional costs for fossil fuel generators would have major implications for the generation mix, putting offshore wind and other renewables at a cost advantage.

There is ongoing debate on the details of the scheme, including the way in which initial allowances will be allocated, the volume of initial allowances, which greenhouse gases will be included and penalties for non-compliance. It is crucial details such as these that will determine if the scheme is effective in achieving long-term carbon reductions, and in encouraging zero carbon generation alternatives.

Case study
The IPCC

The Intergovernmental Panel on Climate Change (IPCC) was formed jointly by the World Meteorological Organisation and the

United Nations Environment Programme as an expert body responsible for reviewing and assessing the science of human-induced climate change.

The IPCC publishes periodic Assessment Reports which communicate to policy-makers and others the most up-to-date understanding on climate change and its impacts. The last one to be issued, the 2001 Third Assessment Report, consists of three volumes, one of which, 'Mitigation' (shown in Figure 6.1), reviews the options available for reducing and limiting the emission of greenhouse gases.

Commenting on the wider benefits of greenhouse gas reduction measures, the report states that 'Climate mitigation policies may promote sustainable development when they are consistent with ˘ broader societal objectives. Some mitigation actions may yield extensive benefits in areas outside of climate change: for example, they may reduce health problems; increase employment; reduce negative environmental impacts (like air pollution); protect and enhance forests, soils and watersheds; reduce those subsidies and taxes which enhance greenhouse gas emissions; and induce technological change and diffusion, contributing to wider goals of sustainable development.' [38]

At the February 2003 session of the IPCC, in Paris, the French Prime Minister J.P. Raffarin stated that 'the performance of the country must not be the only criterion for the GNP. We cannot base our development on the exhaustion of our fixed capital – our natural resources. We must take into account this essential factor, environmental capital, when we calculate national prosperity and, in this way, determine new indicators that will enable us to guide this new action. Creating 50 units of national prosperity is, I believe, naturally very important, but if that is to destroy 100 equivalent units of environmental capital, then it is neither efficient nor acceptable. We cannot pass a degraded situation on to our children and grandchildren.' [39]

6.4 Conclusions

A comparison with conventional generation costs shows that onshore wind energy is already cost-competitive with new coal, IGCC and nuclear power, and can be cost-competitive with other conventional power sources. This is a testament to the cost reductions the onshore wind industry has achieved through economies of scale and technological development over the last decade. Furthermore, when carbon abatement is the primary goal, offshore wind energy is already seen as an attractive option.

As onshore wind has achieved cost reductions, so offshore wind, given the chance to achieve economies of scale, is expected to reduce its costs. When making decisions for the future, it is also important to appreciate the confidence in expectations of different technologies, and the UK's *Energy Review* concluded that offshore wind power costs could be predicted as confidently as those for future nuclear power and coal-fired generation. This was in the context of predicting that offshore wind could outcompete, in conventional terms, both coal and nuclear power by 2020.

The generation of electricity also generates costs that are not presently accounted for in the conventional cost of electricity, or indeed captured at all by our present accounting system. Crucially, when even a selection of these costs is attributed to different energy sources, wind and other renewables clearly incur the lowest total costs to society.

The inadequacies of our accounting and pricing system in properly incentivising wind power and other renewables is increasingly plain. This is why specific support for renewable energies is justified at the European and EU Member State levels.

Clearly the ideal outcome is full internalisation of external costs, but there are inevitable difficulties in achieving such a perfect market, not least of which is the accurate assessment of external costs. There have been some positive developments in taking a pragmatic approach to internalising external costs, ranging from market support mechanisms to the impending European-wide carbon trading regime. Nonetheless, there is a long way to go properly to reflect the true costs of the alternatives and to put wind power on a level playing field with conventional technologies.

The need to take action early in order to achieve cost reductions up to 2020 is widely acknowledged by policy-makers, and although they represent a good start, there is not as yet a clear view on how offshore wind will benefit from anticipated market-based measures, or even if these measures will prove effective. As stated in Section 4.1, new tradeable certificate markets are still seen as relatively novel, and there is not yet enough confidence against which large-scale offshore wind projects can be developed, especially at the scale envisaged in Sea Wind Europe.

There is a need to provide a clear view on how new market-based measures will lead to the development of real projects. It is also imperative that anticipated and new measures are introduced with urgency, if the benefits are to be realised within a 2020 timeframe.

There are also significant gaps in the extent to which externalities are internalised, and work on progressing this should be continued and widened to ensure that the full range of social and environmental costs is included.

7. Electricity grid

An expansion in offshore wind energy of the scale considered here would inevitably require investment in the physical grid network, and an adoption of emerging and new practices for operating the overall system. These reinforcement and system issues are two distinct effects which are considered separately here.

7.1 Reinforcement and extension

Wholesale adoption of offshore wind energy will require new power lines and reinforcement of existing grid routes. This is in the context of ongoing development of the system to meet demand, generation and liberalisation (and hence electricity trade) trends.

The Union for the Co-ordination of Transmission of Electricity (UCTE) is concerned with ensuring transmission system security across 20 continental European countries. Its annual 'system adequacy forecast' determines whether system development plans are adequate for the maintenance of system security. The latest (December 2002) forecast, for 2003–05[40], takes into account plans for new generation plant and transmission lines.

For the UCTE region as a whole, forecast generating capacity increases from January 2003 to July 2005 comprise for the most part fossil-fuel-based energy (largely CCGT) with an increase of 14.4GW, and renewable energy (principally wind) with an increase of 10.9GW. So clearly wind energy is set to be a major component of new power supplies already.

A number of studies have attempted to identify system reinforcement and extension costs attributable to defined increases in renewable energy (for an example, see the British case study below). Inevitably, these costs will be higher than if existing power station locations are used for new power stations.

Equally, there are safety reasons dictating the location of some power stations, and conventional fuels are increasingly imported from very distant locations. In an assessment of fuel supplies to 2020[41], the IEA states that 'The principal uncertainty in global energy supply prospects is cost. Advances in technology and productivity are driving production and transportation costs lower, but the depletion of the cheapest reserves and the growing distances over which new supplies must be transported are, in many cases, pushing delivered energy costs up. The cost of supplying natural gas to the main markets is starting to rise with the depletion of near-to-market reserves and the growing need to ship gas from further afield. On the other hand, renewable energy resources, which are usually exploited at a local or regional level, are generally becoming less costly to produce.'

Furthermore, offshore wind locations are often close to centres of demand. The maps presented in Section 3.4 show major centres of population in relation to possible offshore wind farm locations.

If offshore wind energy is to make significant inroads into European power supply, it makes sense to consider the development of the grid, onshore and offshore, in a strategic manner, rather than let the existing grid drive the locational development of offshore wind energy on a project-by-project basis. There is some evidence that this is already taking place, through national and European initiatives (see the TEN case study below), but the effects to date are marginal compared to what would be required efficiently to drive a massive increase in offshore wind energy.

There is a significant role for EU Member States to play an active part within their own jurisdictions to ensure that necessary extensions and upgrades to electricity networks are delivered to the benefit of wind power. Meanwhile the EC is in the unique position of being able to take an EU-wide view of the issues and ensure that strategic grid infrastructure is co-ordinated and realised in the context of plans for offshore wind power.

Case study

The Trans-European Energy Networks (TEN) initiative

The EC provides financial support for electricity and gas infrastructure through the TEN programme. Since 1994, the EU has supported the construction of energy infrastructure to achieve social benefits, accelerate the development of the internal market and improve security of supply[42,43]. Priorities drawn up in 1996 for electricity infrastructure were to improve interconnections between member states and with other European countries, and to connect isolated networks.

Total community finance provided to electricity and gas networks between 1995 and 1999 is shown in Table 7.1[44].

Of the TEN budget line figure, 38.1% was allocated to electricity, 6% of which was spent on connecting isolated networks, 25% on improving flows between member states, and 69% on connections with other European countries and the Mediterranean.

Table 7.1 Energy infrastructure financial support

Type of assistance	Instrument	Total, 1995–99, € million
Loans	EIB	3,507
Guarantees	EIF	291
Grants and co-financing of studies	Structural funds TEN budget line	1,985 93

In 2001, the EC issued a proposal to amend the guidelines for funding the TENs. Two new policy priorities have been introduced, one concerned with market bottlenecks, the second with 'connecting renewable energy production to the interconnected network'. This new emphasis on renewable energy is carried throughout the proposed new guidelines, and reflected in a number of proposed new 'projects of common interest'. For instance, there are proposals for connections in the north-east and west of Spain 'in particular to connect to the network wind power generation capacities', and to allocate funds to 'adapting the methods of forecasting and of operating electricity networks required by the functioning of the internal market and the use of a high percentage of renewable energy sources' [45].

The integration of renewables into the mainstream infrastructure energy programme of the EC is a significant and necessary development. If carried out, it is measures such as this that will assist in transforming renewables from a niche to an everyday technology across Europe.

7.2 System issues

System issues is a general term that refers here to practices related to operating the grid network in order to maintain a continuous (within defined limits) and acceptable quality of supply. Wind energy is often cited as challenging in this respect, for two main reasons: it introduces variability additional to that of demand; and it does not provide 'ancillary services' – technical generator capabilities which, when called upon, help to maintain power quality. Losses on the system are also discussed – depending on its location, a generating station can increase or decrease losses incurred in the distribution and transmission of electricity.

Table 7.2 provides a context for electricity system development in the EU 15. It shows predicted installed capacity and electricity demand from the EC's European Union Energy Outlook to 2020, and installed capacity and generation in the scenarios postulated in Chapter 3.

This compares to energy penetration in the Danish Eltra[46] system of approximately 16% over a year, and capacity penetration of 30%.

Table 7.2 EU 15 electricity system development predictions

	2010	2020
Energy Outlook predicted total capacity (GW)	717	872
Postulated offshore wind scenario (GW)	27	240
Energy Outlook predicted total demand (TWh/year)	2,673	3,124
Postulated offshore wind scenario (TWh/year)	82	720
Capacity penetration of offshore wind	4%	28%
Energy penetration of offshore wind	3%	23%

Up to a certain penetration, wind energy does not generally pose any major issues for system operators. This is because: the variability on all timescales is insignificant compared to that of demand; wind capacity is small enough to be discounted in considering reserve margins; and services provided by other generators are sufficient to maintain power quality. The point at which system operation becomes difficult depends entirely on the system – its size, generation mix, demand distribution and so on. 20% is often quoted as a benchmark.

This is however highly dependent on the specific situation – isolated small systems may experience difficulties well before 20%. In Crete, for instance, wind energy output is starting to be curtailed at 10% penetration, although this figure is somewhat distorted by the highly seasonal use of electricity on the island. Some very small isolated wind-diesel systems such as that on the Isle of Muck in Scotland can easily experience very high penetrations (reportedly as high as 78%)[47].

There are no overriding technical reasons why wind energy could not achieve close to 100% penetration – it is economics that will determine the ultimate mix. As discussed, the particular challenges that are encountered are very dependent on the specific circumstances of the system, but there are comparisons which can be made between systems in terms of the types of challenges – be they related to power quality, energy balancing, curtailment or otherwise.

The case study on Ireland details an investigation into the issues that the Irish grid can expect to encounter as penetration of wind energy increases, and the appropriate solutions. As well as purely technical solutions, some problems can be solved by changes in the rules that govern access to the grid (grid codes and other requirements).

Even without wind energy, system operation is challenged by variable demand and generation. It has largely developed with an ethos of serving demand, with generation and the network contributing to stability. Different types of generation make different contributions – nuclear is inflexible baseload, hydro with storage is valuable for rapid responses, while coal plant can provide medium-term flexibility to cope with demand changes on a daily timescale. Systems with large, concentrated units are more susceptible to an 'event' of loss of power, whereas a diverse system is inherently more reliable. The grid acts to transmit and distribute, but also to provide a robust system that can absorb the vagaries of all the different connectees, and of the grid itself.

Increasingly, markets and economics influence the extent to which technologies contribute to the operation of the network, and demand is also starting to play a role in this. Wind energy is a relatively new technology, and so will by virtue of this fact alone necessitate changes in system operation. Its disadvantages at present relate to there being no output during low winds, the variability of its output, and the difficulty of predicting that output.

As wind energy's contribution increases, there is an ongoing process in which both the network and wind energy technology are moving towards meeting on middle ground. The network needs to alter its operating practices and plans the better to accommodate wind energy, while wind energy technology needs to adapt the better to meet the needs of an integrated network.

Examples of the former are network operators moving over to more active management of their systems, or adopting new planning and security criteria that better reflect the characteristics of wind energy (rather than ignoring it altogether). The key example of the latter is ongoing development of turbine technology such that wind turbines more closely resemble conventional power plants in terms of services offered. This development is already being progressed through specifying wind turbine requirements in grid codes. GH has previously reviewed a number of proposed new grid code requirements for wind farms[48], and concluded that most can be met for an insignificant effect on the cost of energy.

The use of forecasting tools is beginning to improve the predictability of wind energy output, and new storage applications for use in conjunction with wind power, or as part of the wider system, are beginning to appear on the market. In the short to medium term, storage for grid applications will probably be based on energy carriers such as conventional chemical storage. Hydrogen offers promise but further research is still required.

Case study
Eltra

Eltra is the Danish transmission system operator (TSO) for Jutland and West Denmark, and probably experiences higher wind penetrations than any other major TSO in the world (an annual energy penetration of 16% in 2001, instantaneously in excess of 100% on occasion). Because of market conditions, Eltra has had little control over the wind power plant in its area, and has relied on interconnections to Norway, Sweden and Germany to manage production variability. Recently, though, and partly in response to the introduction of one large offshore wind power station at Horns Rev (as opposed to the relatively dispersed and small onshore wind farms), Eltra has started to ask wind farms to turn into 'Wind Energy Power Plants'. This effectively means that the output from turbines will be more actively managed and controlled, and will start to provide services to the TSO similar to some of those provided by conventional generation.

Eltra has initiated various investigations to further this trend, and is also reviewing the feasibility of provision of a fuel cell storage facility. Commenting on the twin evolution of both turbine technology and TSO practices, Eltra says that 'the wind energy power plant and the demands on it are far from their final form. This will depend very much on the development – both regarding turbines and grid connection. ˇ The connection conditions will thus be revised at regular intervals.'

Eltra concludes: 'Due to the large and increasing share of wind energy power plants, it has been necessary to create new concepts for the incorporation of wind energy in the electricity grid. Not only the size and production opportunities make it interesting to operate the new large offshore wind farms as "wind energy power plants". Also new technology and innovation enable wind farms to considerably function [sic] as power plants meeting a major part of the control requirements made on traditional power plants.' [49]

Case study
Great Britain grid-related costs

As part of its programme of delivering increases in renewables penetration by 2020, the UK Government commissioned a study to investigate the additional network costs that penetration of up to 30% might incur for the British network. The so-called SCAR report (System Costs of Additional Renewables) estimated any additional costs associated with transmission reinforcement, transmission losses, distribution network reinforcement and management, and system balancing[50]. The study examined costs for different mixes of renewables generation for penetrations of 20% and 30% in 2020. Costs were estimated from a starting point of 10% renewables penetration in 2010, and as additional to an alternative baseline of all new capacity being met by conventional gas-fired generation.

Additional costs were estimated in the range £0.30–£0.90 per MWh for 20% penetration and £0.80–£2.20 per MWh for 30%. The lowest estimates corresponded to a mix of baseload renewables and close-to-market wind energy, with the highest costs incurred by large amounts of wind energy distant from centres of demand. For the lowest estimate for 20% penetration, transmission reinforcement costs were actually lower than the baseline scenario, with balancing and capacity costs making up over 90% of the additional costs, and distribution costs the remainder. For the highest 20% estimate, balancing and capacity costs were still the dominant cost element at 71%, with transmission reinforcement at 23% and distribution at 6%.

Building on the outcome of this and other work, a joint paper by the SCAR report authors, NGT[51] and an independent consultant, 'A shift to wind is not unfeasible', looks at an all-wind 20% penetration, compared to a conventional gas generation scenario. 60% of the wind capacity is assumed to be transmission-connected offshore wind. The central estimate for additional costs of this 20% wind scenario is £3 per MWh, which corresponds to an approximate 5% increase on domestic prices.

While inevitably further detailed investigation could refine these estimates up or down, depending on generation plant capital costs, gas prices and so on, the key message is that the general range of additional costs estimated is well within the realms of cost variances associated with other factors, such as VAT.

Case study
Increasing penetration of wind energy in Ireland

The number of wind farms seeking connection to the electricity systems in the Republic of Ireland and Northern Ireland is increasing, and this trend is expected to continue. The anticipated levels of wind generation both onshore and offshore may well exceed, in percentage terms, the levels currently experienced in Eltra's and other systems with high wind penetration. System operators are concerned about the potential effects on electricity systems, and wind farm developers are concerned that network restrictions will cause delays or add cost to new wind farms.

In response to these concerns, the electricity regulators for the two Ireland jurisdictions commissioned an independent assessment from GH, with ESBI and University College Cork, in order to establish the effects of increasing penetrations of wind energy, and propose appropriate action to overcome any adverse effects[48].

The study found that there were two fundamental types of factor that limit the capacity of connected wind generation on the combined systems: transmission planning criteria, and curtailment of wind production due to the requirement to continue to run conventional generation.

Transmission planning criteria determine the amount of generation which can be connected to the system and deliver its rated output without the transmission system's operating limits (e.g. voltage levels, thermal loading limits, stability limits, etc.) being infringed in the presence of predefined abnormal situations (called contingencies) on the system. These contingencies vary in their severity and likelihood of occurrence.

The report suggests that to limit wind power capacity in this way – i.e. to define its ability to connect with reference to unlikely occurrences – is unrealistically restrictive. It proposes instead that the maximum size of wind farm be that which can be connected to the intact system (i.e. with no contingencies), but that if, in the event of a contingency, the presence of wind generation causes any infringement of the preset operating limits, wind generation should be immediately and automatically disconnected.

Curtailment of production refers to the need to limit wind power output at certain times. As the output of wind generation is increased, the output of the conventional generation running at the time is reduced. Eventually the conventional generation will reach a limit below which its output cannot be reduced for technical reasons. When this limit is reached, the output of the wind generation must be reduced ('curtailed') instead. This curtailment clearly has economic consequences. The report recommends that alternative operating strategies be studied in the near future, so that preferred strategies can be in place before wind penetration reaches a level where the economic penalties of wind energy curtailment are significant.

In essence, the study found that while current practices are the product of a system supplied by conventional generation, there is significant scope for accommodating additional wind power capacity without the need for reinforcement or extension of the system. Adoption of new practices and criteria, and thinking ahead, can go a long way towards achieving cost-effective integration of wind power into electricity systems.

7.3 Conclusions

Wind power is a relatively new power source to connect to the network. In most networks at present it constitutes a very small fraction of total capacity or energy delivered. As such, it has not proved worthwhile to make any significant alterations to the way in which the network is planned, built, and operated. It has similarly not been seen as worthwhile to tailor wind power technology to the needs of the network.

Against this background, the default position has been to regard wind turbines as an adjunct to the electricity system as opposed to a part of it. As wind power's contribution increases, this approach becomes neither sensible nor cost-effective. For this reason system operators, planners and turbine manufacturers are beginning to move towards a middle ground. There are signs that future development of electricity systems is, in part, taking into account the likely development of wind power. System operators are beginning to ask for wind turbines that can provide services to the system, and turbine manufacturers are responding to this. Some system operators are even looking at more active management of their networks the better to accommodate wind energy.

These developments are however ad hoc at present. There is no Europe-wide, co-ordinated effort to ensure that networks, and turbine technology, are sufficiently and consistently able to accommodate the levels of penetration envisaged here. For example, GH has recommended to the Irish regulators that grid code requirements for wind farms should adhere to a harmonised European set of capabilities, while allowing jurisdictions to set limits specific to their system. This would mean that turbine manufacturers could develop capabilities for the European market, with the application of these capabilities determined by the grid codes.

If networks are not to be an impediment to achieving the increases in offshore wind power envisaged in *Sea Wind Europe*, offshore wind and its expansion need to be fully integrated into mainstream grid planning. There is an important European-level role in ensuring consistency across EU Member States – which will be essential for delivering cost-effective and timely change – and also in providing for offshore wind in the Commission's own objectives for grid development.

8. Socio-economic

8.1 Prospects

The technology section of this report gives an overview of the types of industry involved in the manufacture of turbines and other equipment and in offshore installation. For the most part, these are familiar industrial sectors such as steel fabrication, shipbuilding, offshore construction and composites. A growing offshore wind sector will support jobs in a wide variety of capacities, including disciplines such as project management, engineering, marine science and meteorology. Some will be local to offshore sites, some will be dispersed throughout the community.

Turbine factory floor

A variety of studies have identified the jobs potential of a growing renewables sector. For Europe as a whole, an EC-funded study initiated by the European Forum for Renewable Energy Sources[53] estimated jobs created as a result of increases in renewable energy to 2020. Carried out over 1998–99, the study predicted market penetration to 2020 of different renewable energy sources, and any displaced conventional generation, the results of which were usedto derive inputs for economic input-output modelling. Direct and indirect jobs were estimated from investment in technologies, also taking into account the effect of redirecting subsidies to renewable energy.

Table 8.1 shows full-time equivalent (FTE) employment creation functions for each technology, derived by the study for 2010 and 2020. Figures for generation technologies represent jobs created by the power stations alone, with the exception of biomass where agricultural sector fuel-related jobs are also listed. Jobs created are divided into construction and installation (C&I) and operation and maintenance (O&M) sectors.

The study concluded that renewables are generally more labour-intensive than conventional technologies. The numbers in Table 8.1, multiplied up to derive jobs created from 720TWh/year of offshore wind energy, suggest a total of 1.6–3 million jobs[54] over the period until 2020 in construction and installation, and 158,400 in operation and maintenance, which would reasonably be expected to be ongoing. Year on year the number of jobs in construction and installation would depend on the rate of installation in that year. The jobs can reasonably be expected to be long-term and stable while the rate of installation is maintained. After 2020, a reduction in installation rate could lead to reduced employment; however the likelihood of continuing long-term jobs is significantly increased by the expectation that turbines would begin to be refurbished and replaced from around 2025 onwards. By comparison jobs in operation and maintenance are long-term and stable for so long as the wind farms continue to operate.

The largest volume of jobs created will be in the manufacturing sector. Some of these jobs may naturally fall close to site (for instance where gravity foundations need to be towed a short distance to site), but some will reflect the attractiveness of a particular region to manufacturers, and the benefits to be gained from local manufacture. The case studies provide examples of benefits for a particular region, and of wind energy compensating for a

Table 8.1 Employment creation functions

	2010		2020		Range	
	C&I FTE/€m	O&M FTE/GWh	C&I FTE/€m	O&M FTE/GWh	C&I FTE/€m	O&M FTE/GWh
Solar – thermal heat	6.40	0.26	6.51	0.25		
Solar – photovoltaic	6.97	0.44	5.38	0.40		
Wind – offshore	7.48	0.22	6.71	0.22		
Wind – onshore	6.06	0.14	6.07	0.14		
Hydro (small-scale)	5.17	0.09	5.21	0.09		
Biomass – liquid	6.08	0.86	6.08	0.86		
Biomass – anaerobic	7.99	0.24	8.31	0.24		
Biomass – combustion	4.41	0.08	4.52	0.08		
Biomass – gasification	6.11	0.09	5.93	0.10		
Fuel production – energy crops	11.05	0.42	11.05	0.42		
Fuel production – forest residues	-	0.10	-	0.10		
Fuel production – agricultural wastes	-	0.36	-	0.36		
Conventional CHP					2.3-5.7	0.02-0.06
Conventional power					4.2-13.0	0.01-0.1
Conventional heating					3.5-15.9	0.01-0.06

decline in traditional manufacturing outlets.

Governments, development agencies, industrial groupings and others are increasingly targeting the renewables sector as a major business opportunity. It is especially apparent to traditional manufacturing sectors that the current decline in business could be reversed by orders from the renewables sector. The case study of the SKET factory in Magdeburg illustrates a type of diversification which is growing. German port authorities in the vicinity of planned offshore wind developments are launching major strategies aimed at attracting offshore wind energy-related business.

Case study
Spain

Installation of wind farms in Spain has seen a dramatic rise over the past few years. From some 46MW in 1995, installed wind power capacity reached 4,830MW by the end of 2002, with just under 1,500MW installed in 2002 alone. Regional targets suggest there will be at least 10GW installed by 2010. This volume of development has been encouraged by ambitious targets, supported by regional and national development policies and a premium price tariff.

Spain has been very successful in capitalising on this growth through local manufacture. Spain's biggest wind turbine manufacturer, and in 2002 the world's fifth largest manufacturer by volume, is Gamesa Eolica. It began in 1994 as a joint venture company between Vestas and the Spanish aeronautics industry manufacturer Gamesa. The company is now 100% owned by Gamesa, has 12 factories and is pursuing an ongoing worldwide expansion. In 2001, wind energy accounted for 52% of Gamesa's turnover, in the context of a growing turnover for the total business.

Other Spanish manufacturers include Ecotechnia, Made, Mtorres and EHN. Foreign manufacturers have also set up facilities in Spain, or make use of Spanish manufacturers. For instance, Nordex (German) manufactures towers at a steel works in Navarra, while the former NEG-Micon (Danish) has a plant at the TAIM factory in Zaragoza. Bonus (Danish), GEWE (American) and LM Glasfiber (Danish) also have substantial presences.

Case study

Greenpeace study – North-East jobs

A study for Greenpeace on the potential for offshore wind-related jobs in the North-East of England55 concludes that the region could benefit substantially from manufacturing contracts. Total net UK jobs to be created from a 10% to 30% 2020 offshore wind contribution to demand were estimated at 24,215 to 75,655 FTE respectively. Over 80% of these jobs would be in manufacture and installation, the remainder in operation and maintenance.

It was estimated that approximately 57% of all offshore wind-related jobs would be in primary manufacturing, with 7% in manufacturing-related sectors such as extraction and processing. Of the remainder, 11% would be in primary services and 25% in secondary services. This spread of potential jobs provides a good fit for the North-East region which is characterised by 'well-established capacity in manufacturing industry' and a relatively high unemployment rate among the industrial workforce.

Case study

Enercon at the SKET factory, Magdeburg, Germany

SKET and its predecessors have been involved in engineering manufacture in Magdeburg since 1855. Initially concerned with shipbuilding, the company's activities diversified over the years into rolling-mill equipment, steel fabrication, lifting equipment, cement plant, edible oil extraction equipment and military products. By 1989, SKET was the region's biggest company, employing 30,000 people in 18 factories. Massive job losses followed German reunification as the company's Eastern European markets disappeared, and in 1996 SKET filed for bankruptcy.

In 1997, SKET's engineering arm, its largest operation, was privatised and purchased by the German wind turbine manufacturer Enercon. Since then the Magdeburg factory has experienced a turnaround in prospects, with employment increasing again. Figure 8.1 shows the SKET factory in Magdeburg.

Figure 8.1 SKET factory

8.2 Conclusions

Offshore wind energy – from planning, designing and building the wind farms, to connecting them to the grid and maintaining them during operation – generates jobs. Per unit of investment, it has the potential to create more jobs than conventional power sectors, and these benefits will be realised to the full where the volume of development is sufficient to sustain an industry over the medium to long term.

Furthermore, because the manufacture of wind turbines, offshore support structures and other products utilises a number of established skills and facilities from the heavy engineering sector, wind energy can offer employment and revitalisation for communities suffering from a decline in traditional manufacturing. This has already been borne out in practice, and development agencies and business groupings are now starting actively to seek out wind energy business.

The Spanish case study demonstrates the value to the local economy of establishing a strong domestic market and encouraging local manufacture. Denmark is the most often quoted example of the twin advantages of creating a market and capitalising on jobs and export revenue. Denmark took early and decisive steps to promote a domestic market in wind energy, resulting in an industrial success story in which Danish wind turbine manufacturers have been at the head of the world market.

This kind of industrial success is the direct product of a national commitment to an industry, and the foresight both to anticipate and benefit from a potential growth business. Economic benefits are realised through targeted policies – to generate a market, to support the skills base and to attract facilities. Otherwise, the benefits will flow to wherever such measures are implemented elsewhere.

9. Public acceptance

Naturally, in a democratic society, public acceptance is vital to the ultimate success of any initiative. The high-profile campaigns of the environmental movement are testament to this fact. Wind power does experience some public opposition, which, if truly representative, can be expected ultimately to halt its development. But actual experience and research suggest that the vast majority of people are supportive of wind energy. This section reviews some of the research into public attitudes, and some examples of engaging people in individual developments.

9.1 Public attitudes

The Eurobarometer survey quoted in Section 1.2 clearly shows that the European general public is by and large environmentally conscious and supportive of technologies such as wind power. The real test of this sentiment is the public's acceptance of projects, and almost all reviews show a majority in favour.

For example, in July 2003 a review by the British Wind Energy Association (BWEA) of opinion polls in the UK between 1991 (when the UK's first wind farm became operational) and 2002 revealed an average of 77% of people supportive of wind power or a particular wind power project[56] – a level of support sustained over the whole ten-year period. The polls reviewed included wind farm open day surveys, opposition group questionnaires and a government-commissioned attitudes survey. Before and after surveys showed higher levels of support after the wind farms were constructed. A separate survey in 2003 of electricity bill payers found that 74% supported large increases in wind power in the UK.

These results agree with another review by the Danish Wind Turbine Manufacturers' Association[57], which indicates a similar theme of familiarity reducing the level of negative attitudes towards wind farms. It includes the results of polls in Denmark, Germany, the UK and Canada. For a relatively new, environmentally motivated technology, these findings are perhaps unsurprising.

Provision of basic independent information on wind energy should facilitate sensible, as opposed to defensive, debate. In its offshore wind strategy, the German Government states its intention to initiate a public information campaign to accompany an offshore wind programme.

If offshore wind is to become as commonplace as the 240GW aspiration here suggests, then perhaps the strong feelings at either end of the spectrum will be replaced with a core of indifference. There are already signs that a more mainstream attitude is being adopted by major utilities, with the likes of Shell and GE for instance advertising their wind energy credentials in commercials[58].

Case study
Schleswig-Holstein, Germany

Motivated by a desire to understand the impacts of wind farms on tourism in Schleswig-Holstein, a collection of interested parties – including the Schleswig-Holstein Tourist Board, the Lübeck Chamber of Commerce, and the regional wind energy and energy foundation – commissioned a study to review data on visitor numbers and public attitudes[59]. At the time at which the study was undertaken, Schleswig-Holstein had the second-largest number of onshore wind farms in Germany. At the same time it is one of the most important holiday destinations in the country, known in particular for its extensive sandy beaches.

The study compared overnight stays at tourist resorts with different numbers of wind farms nearby, undertook questionnaires among the general German population and visitors to Schleswig-Holstein, and conducted some in-depth group discussions.

The review of overnight stays showed no relationship to the number of nearby wind farms. That is, wind farms were having no negative effect on overnight visitor numbers at existing resorts. Taking these results with the outcome of the questionnaires and group discussions, the authors found that 'the results of the study conclusively show that the fear that the presence of wind farms would lead to perceptible damage to the tourist industry is not proven'[60] and that 'even a further increase in wind power would not be rejected out-of-hand by visitors. The majority of those questioned would in fact welcome it.'

Interestingly, the results of the group discussions in particular suggested that the views of the local population could be an important factor. The authors concluded that 'the attitude of the local population plays a role that cannot be underestimated. Committed protest against feared problems from wind farms could possibly lead to a self-fulfilling prophecy about the negative impact of wind farms on the attitudes of visitors. A bold and positive stance on wind power in holiday resorts, if complemented with tourist marketing of the attraction of a "wind park", could possibly establish a competitive edge over other holiday resorts.'

9.2 Community involvement

Every wind farm will be required to seek some form of planning permission, and inherent in this process is affording the local community an opportunity to appraise and comment on a proposed development, or on a wider development plan for an area. Most developers will be proactive in promoting their project through open days, information leaflets and websites. A community fund will also usually be set up should the wind farm be realised.

Outside this normal practice, other forms of community involvement seen in Europe include:

- financial share offerings relating to a project or portfolio;
- tax or other financial incentives to invest in wind energy;
- community promotion of a project; and
- co-operatively-owned wind farms and wind energy companies.

Much of the quoted evidence for the benefits of community participation comes from Denmark, where tax rules promoted private investments in turbines, and where co-operatives and municipally-owned utilities are commonplace. A 1997 survey in a Danish municipality where over 90% of local supply came from wind energy[57] concluded that those with an investment in a turbine were more likely to be supportive of wind energy. It is unsurprising that where an individual has taken the decision to invest, he or she will be supportive. There is however no analysis which shows whether this results in an overall improvement in approval ratings. Naturally, an investment opportunity is welcome, but not everyone will be able to, or want to, use their own money in this way. At any event, opportunities for individuals to invest in wind energy and other environmental technologies are likely to grow over the next decade, as they move into the mainstream.

So there are a number of means by which communities are enfranchised. Wind energy differs from other forms of power generation in its vast range of scales, from single domestic turbines to commercial-scale offshore wind farms. However, simply because of the scale of offshore wind developments and the consequent levels of investment required, some of the smaller-scale examples of community involvement in onshore wind power will not be replicated offshore.

Case study
Co-operative finance

The Middelgrunden offshore wind farm, off Copenhagen, is widely cited as an example of community ownership. It is part-owned by a co-operative, members of which are mostly local to the Copenhagen area. It is especially interesting to explore the circumstances under which a co-operative with no financial resources funded the construction of its half share of the wind farm.

Middelgrunden consists of twenty 2MW turbines, and became operational in 2001. Ownership is 50/50 between the wind farm co-operative (set up expressly for the purpose) and the local electricity utility, Copenhagen Energy (which is owned by the Municipality of Copenhagen). Ownership terms, negotiated over two years, are set out in a contract between the two parties, which allocates ten specific turbines to each party.

A grant of €680,000 from the Danish Energy Agency, and €67,000 from sale of share reservations, funded initial feasibility investigations for the wind farm, and the organisation of the co-operative itself.

Construction finance was raised through sale of shares. The co-operative sought credit for potential shareholders, but was unsuccessful in securing the necessary finance from major institutions. Offshore wind was simply not a priority area for the banks, or they were discouraged by the administration of numerous individual loans.

Offers were, however, accepted from two smaller banks specialising in shareholder finance – Ringkjobing Bank and Faelleskassen Bank. Loans were at 7.4–7.45% over 10–15 years, secured against the wind farm. Co-operatives are common in Denmark and finance for shareholders is not unusual – in this case it was probably the nature and size of the development which presented a challenge. In the event, under 5% of shareholders availed themselves of these loan facilities.

The budget cost for the whole wind farm was €46 million, the actual cost €48 million (the increase being due to higher than expected foundation costs). The co-operative was therefore responsible for financing its €24 million share. Each member of the co-operative is jointly and severally liable, but the risks are reduced through insurance. Until 1999, only those in the municipality could purchase Middelgrunden shares, but they are now open to anybody, with certain conditions. The majority of shareholders reside within the Copenhagen area. (Information from[61] and[62]).

9.3 Conclusions

Public acceptance is imperative for any industry, and offshore wind energy is no exception. Public attitude surveys consistently show majority support for wind energy. However, its novelty value contributes to some misconceptions. The fact that before and after surveys show improved approval ratings after a wind farm has been established suggests that direct experience is valuable in allaying any such misconceptions.

Wind energy's green credentials probably play a part in some of the actively positive reactions it invokes. However, some evidence shows that 'prompting' can turn an otherwise indifferent attitude to a negative one. This suggests that the provision of impartial information on offshore wind energy, at the outset, could be very helpful in engendering support and in allaying fears.

Mechanisms that, one way or another, allow an enhanced level of community involvement in a project can engender support. Specifically, the opportunity to take a financial stake in projects is becoming increasingly common. Insofar as this provides choice and opportunity, it is welcome, but there is no evidence to suggest that it should be a prerequisite for a successful project. The planning process, and established practice, both provide for public involvement in projects, increasingly so as practice develops.

There is an ongoing role for governments and the EC to monitor public acceptance, ensure and promote good practice and provide impartial information and advice to all interested parties.

10. Actions and conclusions

This report has assessed Greenpeace's question as to whether 30% of current EU demand, around 720TWh/year, could be met through offshore wind generation by 2020, and what steps would be necessary for this to happen. This aspiration, translating into 240GW of installed offshore wind capacity, presents a challenge, but one that should be surmountable, and be seen in the context of the challenges that would be posed by pursuing a business-as-usual strategy.

The report has systematically considered some of the key barriers which, if not addressed, would certainly stand in the way of achieving this aspiration. There is a clear set of actions in a number of key areas, such as finance, ongoing R&D, electricity grid development, strategic planning and wind energy market development and stability, that policy-makers and other stakeholders at EU and Member State level must address for very large-scale offshore wind to succeed.

10.1 Actions

Table 10.1 lists objectives taken from each chapter of the report, which are supplemented by actions and suggestions for implementation. These actions are derived from research conducted for the report. There will inevitably be additional useful actions that are not identified here – it is not an exhaustive list, but it does reflect what should usefully be initiated, at the earliest juncture, to prepare for any ambitious programme of offshore wind energy.

It is essential that there be implementation across the board. Any one barrier could compromise the achievement of targets. This suggests the need for cross-departmental co-ordination, giving an agency or an individual responsibility for delivering the overall plan for each Member State, and for the EU.

Table 10.1 Actions to facilitate growth of offshore wind energy

Objective	Proposed action	Possible implementation
Growth rates Establish framework for siting offshore wind farms	Establish planning and consenting procedures for offshore wind energy	EC: • Encourage and assist Member States to put in place necessary planning and consenting regimes Member States: • Work towards an effective consenting regime for areas within and outside territorial waters: this means ensuring existing procedures are adequate, and implementing procedures for non-territorial waters where they are not in place
Resource and development scale Provide feasibility-level resource information	Support projects which seek to harmonise and disseminate GIS data; encourage data compilation	EC: • Give financial support through Framework 6 and Intelligent Energy programmes • Support dissemination of data among data holders such as European Environment Agency, maritime and mapping organisations, and the EC itself Member States: • Give financial support through R&D funding • Support dissemination of data among main data holders

Objective	Proposed action	Possible implementation
Finance Facilitate commercial finance	Encourage Member States to provide long-term, stable market environments for offshore wind energy	EC: • Build upon the Renewables Directive, ensuring targets are formalised and new, more ambitious targets given formal backing • Map and clarify the impact of new Europe-wide market mechanisms, principally tradeable certificates, on offshore wind energy, and consider provision of early market entry routes into these new markets for offshore wind Member States: • Establish route to market for offshore wind energy • Facilitate supplementary instruments such as price markers and other means by which long-term price can be benchmarked and hedged • Ensure smooth and clear implementation of new market mechanisms such as the European carbon trading regime and new Kyoto mechanisms
	Support demonstration offshore wind farms across a spread of environmental conditions, and utilising a spread of technology solutions	EC: • Give financial support through Framework 6 and structural funds • Facilitate dissemination of the results of demonstration projects Member States: • Give financial support through R&D and regional assistance • Facilitate provision of test centres
	Ensure offshore wind forms a key investment sector for European and other institutional banks, and support the setting up of new institutional banks with an environmental focus	EC: • Set ambitious aims for renewables-related lending for European institutional banks • Encourage renewables expertise within European institutional banks Member States: • Set ambitious aims for renewables-related lending for national institutional banks • Consider role government can play in securing loans for certain projects
	Disseminate information and build confidence in offshore wind energy within the finance community	EC and Member States: • Promote, where appropriate, financial prospects of offshore wind energy • Disseminate financial information from demonstration projects • Support initiatives that aim to build confidence in offshore wind energy from within the finance community
	Support development of new finance contract structures, and promote dissemination of experience in other sectors	EC and Member States • Explore use of new financial structures through institutional banks • Facilitate transfer of experience in alternative financial structures from other sectors

Objective	Proposed action	Possible implementation
Technology Overcome key technology challenges for deeper and more severe environments, and for offshore maintenance	Continue the ongoing review of R&D priorities for offshore wind energy, and target funds accordingly	EC: • Target funds in Framework 6 programme according to common European priorities • Maintain and develop mechanisms for dissemination of results, and feeding back research priorities to inform future funding rounds Member States: • Target R&D funds according to national priorities • Facilitate transfer of solutions from academic to industrial arena
	Support transfer of knowledge and industrial capacity from existing industries	EC & Member States: • Focus support for declining engineering sectors on diversification to renewables, for instance through the newly formed EC programme for coal and steel research • Within the EC and Member State governments and institutions, encourage secondments of technical support staff between sectors, and encourage training in renewables.
	Encourage innovation to meet unique design requirements, and use of novel materials	EC: • Prioritise innovative research within Europe's Joint Research Centre • Encourage novel solutions, where appropriate, within the Framework 6 programme Member States: • Target funds and mechanisms to encourage innovation among the academic and business communities
	Co-ordinate research priorities	EC: • Ensure co-ordination of research priorities across different programmes: while each programme such as FP 6 has established procedures for reviewing and prioritising research, it would seem appropriate to monitor and prioritise offshore wind activities across the different programmes Member States: • Similarly, a co-ordinating role across all offshore wind research activities would avoid duplication and facilitate dissemination
Ensure the provision of adequate component and composites precursor supply capacity for a growing offshore wind sector	Anticipate and fill gaps in supply chain	EC and Member States: • Taking existing offshore wind suppl chain analysis, disseminate findings to key industrial groupings such as the steel industry • Encourage further supply chain analysis within industrial groupings, and ongoing dissemination of findings • Provide financial and practical support for filling gaps in supply chain Member States: • Target regional inward investment and economic development funds to filling gaps in national supply chains

Objective	Proposed action	Possible implementation
Generation costs Lay groundwork for cost reductions	Promote market measures which allow economies of scale	EC • Build upon the Renewables Directive, ensuring targets are formalised and new, more ambitious targets given formal backing • Support and promote market mechanisms which provide for a predictable, stable volume increase (as opposed to periodic, unpredictable 'tranches') Member States: • Implement market mechanisms which provide for a predictable, stable volume increase
	Allow and encourage early investments in support of offshore wind	EC: • When considering applications for state aid, allow Member State-level targeted renewables industry investments aimed at early market stimulation Member States: • Target early investment now to achieve cost reductions in the future
Internalise external costs, or recognise externalities in decision-making	Allow, encourage and implement policies which seek to address market failure to internalise externalities	EC: • When considering applications for state aid, allow market mechanisms which seek to redress market failure • Encourage CO_2 trading and other mechanisms on the grounds of redressing market failure • Support further work to increase certainty as to the value of externalities • Incorporate externalities into the remit of the anticipated new European Regulators Group for Electricity and Gas, such that decisions are taken on the basis of minimising total costs, which include externalities Member States: • Promote renewable energy market mechanisms on the grounds of redressing market failure • Incorporate consideration of externalities into the remit of energy regulators and other market-related bodies, to allow decisions to be taken on the basis of minimising total costs, including externalities
Grid Plan the network with a view to cost-effective integration of offshore wind energy programmes	Expand TEN network plans which provide for offshore wind energy	EC: • Building on proposed amendment of TEN guidelines, prioritise renewable energy-related investment under the TEN programme Member States: • Propose renewable energy-related links to the TEN programme
	Encourage Member States to anticipate and plan the network needs of offshore wind energy	EC: • Via an appropriate instrument – guidelines or legislation – ensure that there is European-level network planning for offshore wind energy and other renewables

Objective	Proposed action	Possible implementation
		Member States: • By requirement or otherwise, ensure that network owners and operators are anticipating significant expansion in renewables • Support network owners and operators in meeting these requirements
Promote increasing integration of wind energy into system operator practices and codes	Provide for harmonisation of grid code requirements and technical standards	EC: • Support the work of European standards committees in development and harmonisation of wind energy technical standards • Encourage organisations such as European Transmission System Operators (ETSO) to promote European-wide harmonisation of grid codes • Consider setting target dates for harmonisation Member States: • Support Member State representation on European standards committees • Require grid codes to work towards European harmonisation
	Promote active network management practices which enhance wind energy penetration in advance of system reinforcement	EC: • Consider merit of a 'best endeavours' or similar requirement which would obligate the consideration of the most efficient means of incorporating wind energy into the grid • Encourage networks to share best practice in connection and integration of wind energy Member States: • Participate in, and support, work to develop and implement active network management for increasing penetration of wind energy • Through existing or new grid access rules, ensure that renewable energy connections are achieved efficiently, and with reference to established best practice
Socioeconomics Retain job benefits of offshore wind energy	Secure job benefits within the European Union and Member States	EC: • Promote establishment of manufacturing facilities within Europe • Through structural funds rules and guidelines, and other appropriate economic development instruments, provide financial assistance for securing job benefits within Europe Member States: • Encourage development agencies to target jobs associated with offshore wind energy • Through planning and allocation of economic development funds, seek to secure jobs associated with offshore wind energy

Objective	Proposed action	Possible implementatio
Public acceptance Improve public understanding and acceptance of offshore wind energy	Facilitate provision of impartial information on offshore wind energy	EC: • Monitor and refine European energy labelling initiatives EC and Member States: • Support provision of independent information on offshore wind energy • Promote greater understanding of offshore wind energy
	Monitor public attitudes	EC and Member States: • Continue to monitor public attitudes

10.2 Conclusions

The offshore wind vision presented here is deliberately bold. It identifies at this early stage the necessary steps that need to be taken. It shows what could be possible for a renewable energy technology, given the right kind of support across the board. It also stresses that actions need to be addressed now if a 2020 timescale is to be met.

Offshore wind utilises existing, mainstream skills and materials in the processes of its development and to deal with the challenges that this development may present. The novelty is in how these skills and materials are used. The technical and industrial know-how for a massive expansion of offshore wind energy is already largely in place. The challenges that remain should be surmountable. They are almost certainly no greater than the challenges presented by the alternative of continuing on a 'business as usual' path for Europe's electricity system.

The remaining barriers to success on the scale described in *Sea Wind Europe* are procedural as well as technical. Political support, backed up by the confidence to take early action, is crucial. Investment and commitment are required to effect a modal shift to renewables. There is a growing recognition that the benefits to society of making this shift will more than justify such a course of action.

In conclusion, providing that all barriers are dealt with and that action is taken in the areas specified, the level of development described in *Sea Wind Europe* could be possible and the far-reaching potential benefits, both social and environmental, be within reach. This vision of what could be possible should provide inspiration for promotion of all the renewable technologies which will be required for a diverse sustainable energy future.

Appendix

Methodology of Sea Wind Europe deployment scenarios

GIS is employed in this study to gain an appreciation of the scale of development implied, through the use of maps as opposed to any more sophisticated attempt to estimate the total resource. Scenario-based maps illustrating a build-up to 240GW installed capacity are shown in Section 3.4 of the report. The process by which these maps were developed is explained in detail here.

A wind speed GIS layer was derived primarily from the 1995 GH/Germanischer Lloyd EC study[13]. Assuming a medium-range deployment density[63] of 8MW/km2 and a power curve from a typical modern offshore wind turbine, an annual energy yield (AEY) was derived for each GIS grid square.

Sea depth and distance to shore are key economic and technical factors which impact upon a project's economic and technical feasibility, and these were taken from a world-wide digital dataset[64] and from computation in the GIS respectively.

It is also instructive to examine the extent to which various planning and other constraints affect the quantifiable resource. Table A1 very briefly summarises typical constraints to offshore wind development, with an explanation of the way in which each might limit development potential. There is a wealth of information on these issues, which have been covered much more extensively in other studies. An EC-funded action – Concerted Action on Offshore Deployment, (COD) – is also in the process of gathering sources of information on offshore wind development considerations in a central database [65].

It is noted that, when investigating a potential site, developers must consider in detail a wide range of constraints, including but not limited to those listed in Table A1. Potential impacts, and their magnitude, are subject to in-depth assessment in both the Strategic Environmental Assessment and the Environmental Impact Assessment processes. The former is an assessment which is carried out on government plans and policies prior to their implementation, the latter an impact assessment carried out by the developer in support of an application for project consent.

Despite an extensive search, no suitable EU-wide GIS datasets were sourced for the constraints listed in Table A1. GH does hold some constraint datasets digitised from sea charts in the previously mentioned 1995 study. However, a check against the most recent UK Hydrographic Office Admiralty Charts confirmed that these datasets were now somewhat out of date.

As a starting point, the 1995 datasets were used to exclude areas from development. The area excluded was largely determined by the resolution of the GIS – a kilometre square. For traffic zones, oil and gas platforms, pipelines and cables, any kilometre square in which their presence was recorded was excluded. For traffic zones, a 1 kilometre square buffer zone was also excluded.

Taking these exclusions, and within bounding assumptions for scenarios to 2010, 2015 and 2020, wind farms were placed, from judgement, offshore of coastal EU 15 countries. This judgement included a checking by eye against Admiralty Charts for any obvious constraints, knowledge of existing and planned offshore wind farm locations, and feedback from Greenpeace offices throughout Europe. Wind farms were placed until the desired energy output for each scenario year was achieved.
This is a purely indicative approach, but was considered sufficient for the present purpose, which was simply to show development scale.

There is no suggestion at all that the resulting locations are where wind farms should, or could, locate.

Table A1 Typical constraints to offshore wind development

Constraint	Description
Platforms, pipelines and cables	Seabed works should avoid the immediate vicinity of underwater pipelines and cables. There are no uniform guidelines on avoidance distances. The International Cable Protection Committee [66] recommends 1 km distance between any seismic survey and an active cable.
Environmental protected areas Visibility of wind farms and landscape/ seascape	There is not always a presumption of complete avoidance, but it is important to ensure the designated interests are not adversely affected. The fact that a wind farm is visible from 'sensitive' locations, and its effect on the surrounding landscape or seascape, can be constraints on its location. There are instances where a minimum distance from shore has been specified for offshore wind farms, to avoid potential conflict on visibility and landscape/seascape grounds.
Military interests	These include practice areas, telecommunications and radar equipment. For practice areas, the extent for co-existence is yet to be fully tested but there are precedents in the oil and gas industries. Impacts of wind farms on telecommunications and radar are subject to site-specific technical assessments.
Civil aviation interests	These include airport approaches and take-off paths, defined routes, telecommunications, and radar and navigational equipment. It is usually necessary to avoid certain areas in the vicinity of airfields. For equipment, as with military equipment, impacts are usually determined through site-specific assessments.
Shipping lanes	There is a variety of shipping routes, some of which are agreed through the International Maritime Organisation, and within them obstructions would cause a hazard.
Commercial fishing	Offshore wind farms can reduce the area available for fishing by virtue of their presence and any exclusion zones around them. It is also important to ensure construction activities do not have an adverse impact on spawning. There may however be a positive impact through the structures acting as artificial reefs and havens from fishing effort (contributing to recovery of stocks).
Communications	Microwave and other communication links for commercial providers, emergency services and other bodies need to be considered.
Aggregate extraction	There is a need to avoid extraction areas while still active, but once abandoned they could form 'brownfield' development sites.
Dumping	Generally, sites where hazardous substances have been dumped should be avoided.

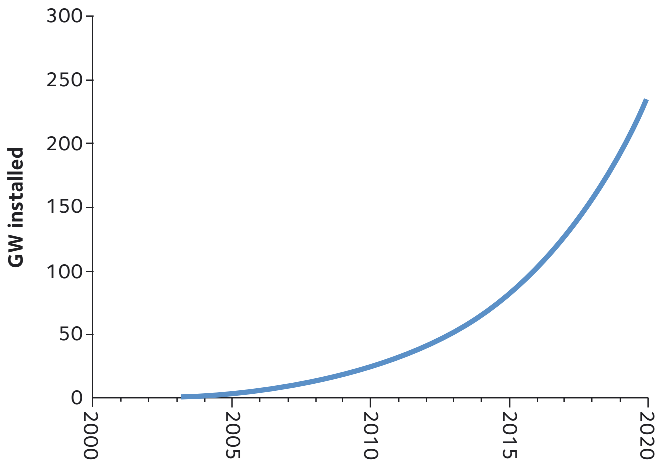
Assuming approximately the growth pattern of offshore wind postulated in Section 2.2, and shown below in Figure A1, three sequential scenarios were considered. These were as follows:

2010: In addition to the considerations described above, wind farms were limited to areas within a band 5–30km from shore, and within 30m depth. The 5km boundary was to reflect a general move by some countries to impose a coastal buffer zone for very large offshore wind farms on visual grounds. The 30km from shore and 30m depth constraints reflect a combination of anticipated technical and cost-related limitations to 2010. On technical grounds, wind farms were placed to avoid locations that experience particularly extreme weather conditions.

2015: As offshore wind farms move into more challenging environments, they might first be expected to move further offshore and to slightly deeper locations, in relatively less exposed areas (rather than shallow but exposed locations closer to shore). For this intermediate scenario, additional area was therefore released by relaxing the depth limitation to 50m and the distance limitation to 5–40km.

2020: By 2020, it is considered that exposed locations may become cost-effective, and hence they are now released for development, as well as areas outside the 40 km from shore constraint, and depths of up to 100m. Even if technology allows, deeper, more exposed and further offshore locations are still likely to be more expensive, and thus a site which combines all three – deep, far off, and exposed – is not represented in this scenario.

Figure A1 Postulated growth of offshore wind to 2020



Endnotes

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[12] A gridded dataset is a geographical dataset with a resolution, meaning it has a value of some kind for every square on the map. It is pixelated data. A contour dataset is contains data in contour lines on a map - an example of the data held in contours might be height above sea level."

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[15] A conservative rule of thumb is to keep eight times the rotor diameter in all directions between turbines, but this can be reduced in non-prevailing wind directions. Proposed densities range from approximately 6 to 12MW/km^2.

[16] Information on the project is available at: http://www.hornsrev.dk/

[17] Thomson Financial, personal communication. Figures derived from database of financed projects.

[18] European Investment Bank, 2001. *EIB Financing of Energy Projects in the EU and CEE countries.*

[19] The project website can be found at: http://projects.bv.com/ebrd/index.htm

[20] Composite figures and commentary compiled by Chris Hornzee-Jones, consulting engineer, supplemented by insight from Adrian Williams of SP Systems.

[21] For simplicity, it is assumed that each blade has the same stiffness. In reality, the all-GRP blade may have a reduced stiffness and hence reduced mass.

[22] End-grain balsa assumed as the core material. It might also be PVC or other foam in which case the mass of the core would be around 1/3 less.

[23] SP Systems and Hexcel are the dominant suppliers of pre-pregs into blades in Europe at present. There are many other suppliers of non-pre-preg materials i.e. dry fabric and separate resin systems for hand laminating or infusion. Thus SP Systems and Hexcel do not represent the total current size of the blade materials market. The current state of the art indicates that neither hand layup nor infusion is going to be practical for carbon fibre. Therefore either pre-preg or another mechanised process such as pultruded reinforcing bars are likely to be used for future carbon blades. So a scenario using carbon in offshore blades would indicate a large growth in this part of the market. Of course, this depends on the carbon fibre itself being available in sufficient quantities – this is the real issue.

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