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# Offshore wind power developments

## An overview of realisations and planned projects

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## Preface

The overview in this report has been compiled by ECN, Unit Policy Studies, by L.W.M. Beurskens (Luuk) and M. de Noord (Manuel), in the framework of offshore wind development activities. The ECN project number is 7.7449.

## Abstract

This report presents the current status of offshore wind power installations based on an extensive literature and Internet research. In April 2003, the installed capacity of offshore wind farms amounted to 279 MW, of which 233 MW in Denmark, 19 MW in the Netherlands, 23 MW in Sweden and 4 MW in the United Kingdom.

Europe is leading in the realisation of offshore wind projects. Therefore, this report focuses on offshore wind projects in this region of the world.

Based on disclosed plans for offshore wind power, a short-term projection for the year 2006 of approximately 3.2 to 3.4 GW has been found and a long-term projection of 24 to 25 GW. For the long-term projects, in most cases a year of construction is not available. A small part of them could even be realised until the year 2006, possibly increasing the short-term realisations.

The countries in which the plans are most promising, based on the planned capacity, are Germany, Ireland and the United Kingdom, which together have a share of over 90% in the total projections.

If investment costs for offshore projects and plans were found, these have been indicated, but this is only the case for a small number of projects.

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# SUMMARY

At present the offshore wind power market is growing very fast. Considering the whole period from the first offshore wind project in 1991 to the last realisation in the year 2002, an average annual capacity growth of 43% can be observed.

This report gives an overview of all offshore wind projects that are currently known. For those projects that presented a time schedule for the construction phases, the cumulative installed capacity by the year 2006 can amount to 3.2 GW to 3.4 GW. Starting with 256 MW by the end of 2002, an installed capacity of 3.3 GW by the end of the year 2006 would mean an *average annual growth* up to 90%.

Many projects are announced without publishing detailed planning information. The total cumulative capacity of all projects, regardless their time schedule, amounts to 25 GW.

A projection until the year 2006 is presented in the table below.

Table S.1 *A chronological overview of European offshore wind projects in the past and in the future[1]. In parentheses, the country names have been indicated*

| Year | Realised | Projected | Average Cumulative installed capacity | |
|---|---|---|---|---|
| 1990 | | | 0 | MW |
| 1991 | Vindeby (DK) | | 5 | MW |
| 1992 | | | 5 | MW |
| 1993 | | | 5 | MW |
| 1994 | Lely (NL) | | 7 | MW |
| 1995 | Tunø Knob (DK) | | 12 | MW |
| 1996 | Dronten (NL) | | 29 | MW |
| 1997 | | | 29 | MW |
| 1998 | Bockstigen (SE) | | 32 | MW |
| 1999 | | | 32 | MW |
| 2000 | Middelgrunden (DK), Utgrunden (SE), Blyth (UK) | | 86 | MW |
| 2001 | Yttre Stengrund (SE) | | 96 | MW |
| 2002 | Horns Rev (DK) | | 256 | MW |
| 2003 | Samsø (DK) | Zeebrugge (BE), Frederikshavn (DK), Nysted (DK), La Rochelle (FR), North Hoyle (UK) | 0.3 | GW |
| 2004 | | Vlakte van de Raan (BE), Meerwind Phase 1 (DE), Kriegers Flak Phase 1 (DE), NSW (NL), Q7-WP (NL), Słupsk (PL), Klasarden Gotland (SE), Utgrunden II (SE) | 1.4 | GW |
| 2005 | | Thornton Bank (BE), Borkum Riffgrund-West Phase 1 (DE), Dan-Tysk Phase 1 (DE), Kriegers Flak Phase 2 (DE), Sandbank 24 Phase 1 (DE), Cabo de Trafalgar (ES) | 3.1 | GW |
| 2006 | | Arklow Bank (IE) | 3.3 | GW |

[1] In most cases, construction works have been planned in a period, for example 2004 – 2006. In such cases, the park is attributed to the last year in the period, in this example 2006.

# 1. INTRODUCTION

## 1.1 History of offshore wind

The first offshore wind farm has been operating since the year 1991: 11 turbines near Vindeby in Denmark. In the years that followed, additional experience was gained with wind farms across Denmark, the Netherlands, Sweden, and most recently also in the United Kingdom.

These offshore wind farms have mostly been built in moderate circumstances: waters that are not very deep (less than 5 metres), wave-regimes that are not extreme, and locations not too far from the coast. This means that offshore wind power from these early projects has been realised at relatively low cost, despite their pioneer character. As offshore wind farms have only been realised in Europe so far, this report mainly presents an overview of this region of the world.

The European Wind Energy Association (EWEA) has set a target of 5 GW offshore wind power by the year 2010. This compares to a target of installed onshore capacity of 60 GW by the year 2010. The total installed capacity in Europe at the end of the year 2002 amounted to 23 GW (see www.ewea.org/src/europe.htm, June 2003). Recently, EWEA adjusted its target for offshore wind power to 10 GW in the year 2010 and 70 GW for 2020 (EWEA, 2003).

## 1.2 Advantages of offshore wind power

Installing wind turbines offshore has a number of advantages compared to onshore locations. At a sufficient distance from the coast, visual intrusion and noise are minor issues. These advantages make it possible for offshore wind turbines to be larger (and thus have more MegaWatt (MW) capacity installed) and less attention needs to be devoted to reduce noise emissions, which entails additional costs for onshore wind turbines. Another advantage is the wind pattern, which is more uniform at sea than on land. A less fluctuating load means a decrease in wear. Wind speed is also much higher offshore than onshore, which means that more electricity can be generated per square metre of swept rotor area.

On the other hand, investment costs are higher and accessibility to the turbines is poorer, as a result of which maintenance costs are higher. Also, circumstances at sea are harder: more corrosion due to salt water and additional load from waves and ice. And obviously, the offshore construction is more complicated to build compared to an onshore foundation.

The amount of space available for offshore wind turbines is many times larger than onshore. The potential for wind energy is therefore also considerably greater. As an example for the Netherlands, based on the area available outside the 12-mile zone (about 22 km) with a water depth of less than 20 metres, there is room for roughly 3 GW of wind power.

The North Sea, boarding the Netherlands, has the advantage of a relatively shallow sea: nearly the entire Netherlands Exclusive Economic Zone (delimitation of the Netherlands Continental Shelf) is less than 50 metres deep. The Netherlands shares this advantage with countries such as Belgium, Denmark, the UK and Germany. Other European countries with an extensive coastline, such as Ireland and Spain, have a relatively small sea area with water depths less than 50 metres. When competition in large-scale renewable energy supply starts between the different European countries, the Netherlands will possibly have a comparative advantage because it has such a large sea area at its disposal.

## 1.3 Projected offshore wind power development

The offshore wind farms that have been realised in recent years are of a different kind than the first offshore experiences in the early 1990s: larger installed capacities (for both turbines and wind farms) and deeper waters.

In the current overview, all turbines that have been installed in water are accounted for as 'offshore'. This is to avoid discussions whether turbines that are placed only a few meters from the shore should be called 'wet-feet'-types or even onshore. This means that projects in inland seas are also mentioned. As can be seen from Table 1.1, 279 MW of offshore wind power has currently been realised (April 2003).

In the year 2003, a limited number of offshore wind power farms are in the planning phase. For the year 2004, however, the amount of projections increases, and a very strong offshore wind power development is expected in the years 2005 and 2006. Table 1.1 also presents an overview of projects in the planning phase.

Due to very fast technical developments in the wind turbine industry, future projects often indicate their projected capacity as a range; today a 2 MW turbine is standard, but in the short-term this is expected to increase to 3 MW or even more. Therefore, the size of a wind farm may be presented as a capacity range. For some projects, turbines of even 5 MW are projected. Currently, these are not yet available on the market; they merely exist on paper or in prototypes. The largest commercial offshore wind turbine today is produced by GE Wind Energy and has a capacity of 3.6 MW.

In the country-specific chapters that follow, the realisations of offshore projects have been highlighted in more detail. Countries that have significant offshore plans are discussed in separate chapters; others are discussed in the final chapter of the report (Chapter 9). Chapter 9 also gives a short overview of projects in the rest of the world.

Table 1.1 *Overview of offshore projects*[1]

| | Offshore wind capacity | |
|---|---|---|
| | Installed until April 2003 | Planned or under construction |
| Belgium | | Minimal 644 MW |
| Denmark | 233 MW | 649 MW |
| Finland | | 180 to 240 MW |
| France | | 1.5 MW, possibly 100 MW |
| Germany | | 6.5 GW until 2006, and much more after that |
| Greece | | Unknown |
| Ireland | | 2 GW |
| Netherlands | 19 MW | 219 MW |
| Poland | | 122 to 183 MW |
| Spain | | 250 MW |
| Sweden | 23 MW | 114 MW |
| United Kingdom | 4 MW | Minimal 2 GW |
| Total in Europe | 279 MW | Minimal 14 GW |
| Projects in rest of world | | 1120 MW |

[1] Realised offshore projects include the year 2002 and the first months of 2003. Commissioning of the wind farms is mostly foreseen for the period 2004-2006

# 2. BELGIUM

Table 2.1 *Projected offshore wind farms in the Belgian part of the North Sea*

| Project | Location | Capacity [MW] | Investment [€/kW] | Commissioning date |
|---|---|---|---|---|
| Seanergy | Vlakte van de Raan | 100 | 2200 | 2003-2004[2] |
| Zeebrugge | Zeebrugge | 28 | | 2003 |
| FINA-Eolia | Vlakte van de Raan | 100-180 | | Unknown |
| C-Power | Wenduinebank | 100 (50 × 2) | 2250 | Permission refused |
| Zephyr | Thornton Bank | 300 | 2000 | Unknown |
| C-Power | Thornton Bank | 216 - 300 (60 × 3.6 - 5) | | 2005[3] |
| Total | | 644 - 808 | | |

The project Seanergy (CPTE and Group of Companies Jan de Nul) of 100 MW (10 MW in 2003, 90 MW in 2004) has been authorised mid 2002, and could possibly be the first Belgian offshore wind farm. Recently, however, the Belgian Council of State forbade the construction works, based on complaints regarding the procedure for the permission granting (Utilities, 2003). For the total wind farm, an investment of € 220 million is required (Electrabel, 2002).

Furthermore, a 28 MW wind farm near Zeebrugge is planned for 2003; 10 turbines will be placed near the shore, 4 will be placed on a dam.

A 100 to 180 MW farm of FINA-Eolia is in an early planning phase, and is projected for Zeebrugge.

The authority has refused a 100 MW farm on the Wenduinebank, planned by C-Power, projected to cost € 225 million (SEV, 2001).

For the Thornton Bank, 27 km off Zeebrugge, two consortia applied. The first consortium, Zephyr, consists of Belgian Shell and SPE Power and projects 300 MW (110 turbines) at an expected investment cost of € 600 million. The second consortium is led by C-Power, which applied for erecting a 300 MW wind farm. Projected are 60 turbines, of which the exact size is not yet known and an annual electricity output of 710 - 1000 GWh (C-Power, 2002).

A schematic impression of the Belgian wind farms is presented in Figure 2.1 and Figure 2.2. Pictures have been taken from Management Unit of the North Sea Mathematical Models (MUMM, 2002; www.mumm.ac.be, December 2002)

[2] The status of this wind farm is unclear at present, due to a recent judgement by the Belgian Council of State. The wind farm has not been included in the total power projection.
[3] Permission has been granted. Internet: www.standaard.be, 24 June 2003.

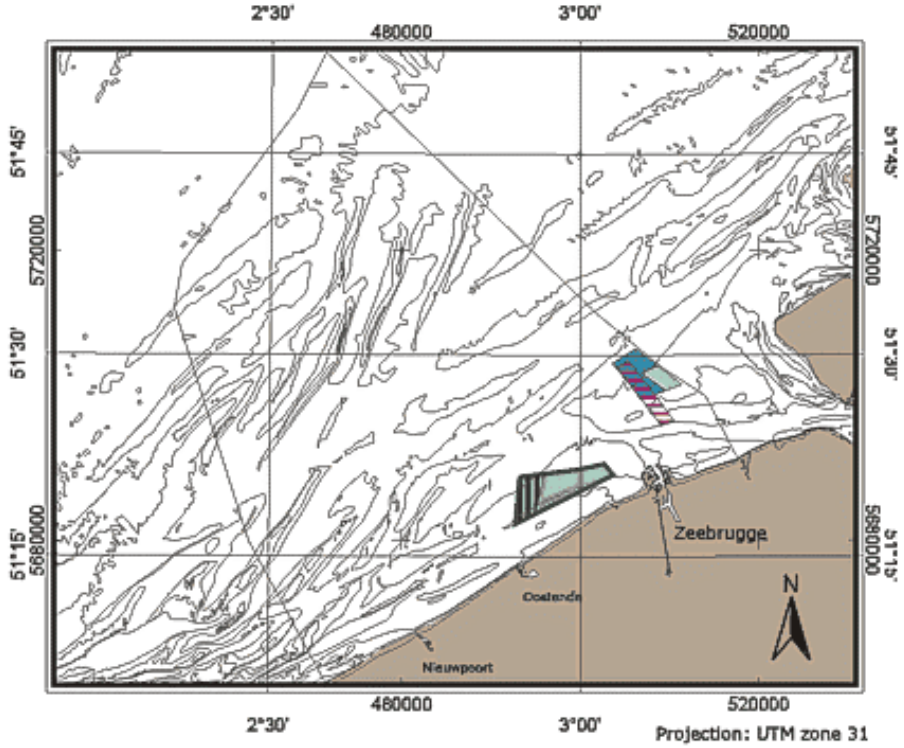



Figure 2.1 *Belgian offshore plans. Projects for Vlakte van de Raan (with the concession areas of Seanergy and FINA-eolia) and Wenduine Bank (C-power concession request which has not been authorised) are indicated (MUMM, 2002)*

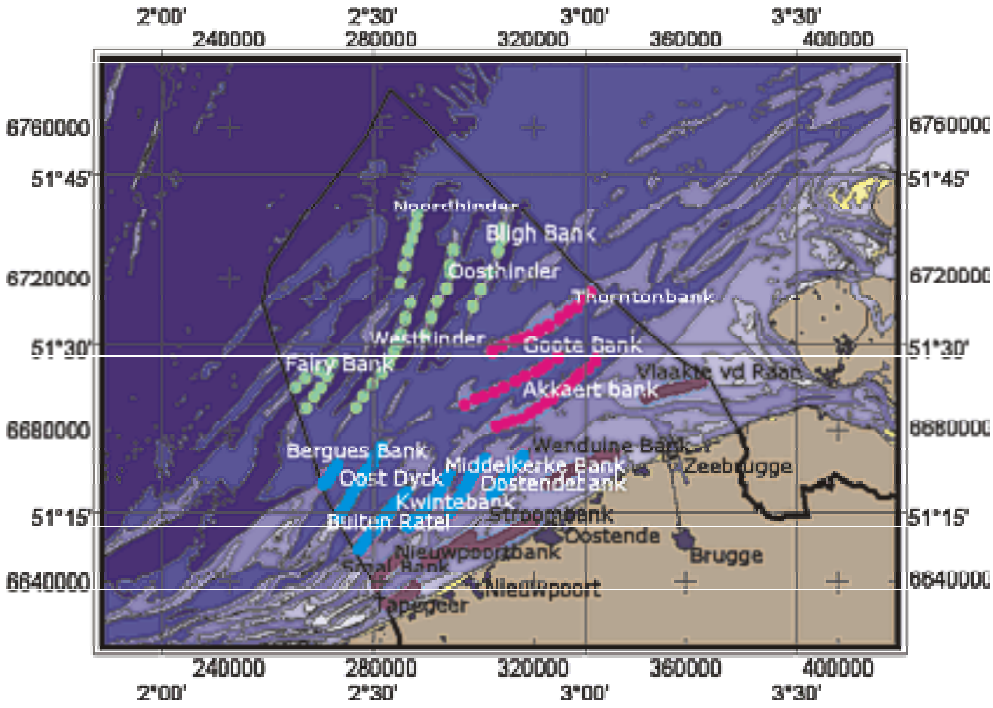



Figure 2.2 *An overview of Belgian sandbanks, including the Thornton Bank (MUMM, 2002)*

# 3. DENMARK

Development of offshore wind in Denmark started in the early 1990s. In Table 3.1 an overview is given of the wind farms that have been realised until April 2003. Future developments are listed in Table 3.2.

Table 3.1 *Offshore wind farms in Denmark*

| Project | Location | Capacity | Investment [€/kW] | Commissioning date |
|---|---|---|---|---|
| Vindeby | Baltic Sea | 4.95 MW (11 × 450 kW) | 2600 | 1991 |
| Tunø Knob | Baltic Sea | 5 MW (10 × 500 kW) | 2300 | 1995 |
| Middelgrunden | Baltic Sea | 40 MW (20 × 2 MW) | 1225 | 2000 |
| Horns Rev | North Sea | 160 MW (80 × 2 MW) | 1675 | December 2002 |
| Samsø | Paludans Flak (Kattegat) | 23 MW (10 × 2.3 MW) | Unknown | January 2003 |
| Total Realised February 2003 | | 233 MW | | |

For the overview of existing and future wind farms much information has been derived from (Lako, 2002). In 1998, the Danish Ministry of the Environment and Energy asked the electricity suppliers to construct five demonstration wind farms with a combined output of 750 MW. In 2002, the newly elected Danish government reduced the Plan of Action for wind energy to include only two demonstration wind farms, those of Horns Rev (operational) and Rødsand (under construction) with a capacity of 160 MW and 158 MW respectively.

*Vindeby*

In 1991, the world's first offshore wind farm was put into operation, consisting of 11 × 450 kW turbines, 1.5-3 km off the coast at Vindeby in 2.5-5 m deep water. The average wind speed is 7.5 m/s. The specific investment cost is established at € 2,600/kW (Lako, 2002).

*Tunø Knob*

The second near-shore wind farm in Denmark is the 10 × 500 kW (5 MW) wind farm Tunø Knob, commissioned in 1995. The distance to the shore is 3-6 km, and the water depth is 3-5 m. The average wind speed is 7.4 m/s. The specific investment cost is € 2,300/kW (Lako, 2002).

*Middelgrunden*

In 2000, the Middelgrunden wind farm (2 km offshore from Copenhagen) was commissioned, comprising 20 turbines of 2 MW each. The water depth is 2-6 meter, and the annual mean wind speed at hub height (64 m) is 7.1 m/s. The expected electricity production is 89 GWh/year, and the investment costs were € 1225 per kW (Lako, 2002; www.middelgrunden.dk).

*Horns Rev*

Elsam A/S has built the Horns Rev wind farm, as agreed in the Danish Plan of Action mentioned before. It is located in the North Sea, 14-20 km from the coast near Esbjerg in 6-14 m deep water. The capacity of the wind farm is 160 MW (80 × 2 MW). The annual mean wind speed is 9.7 m/s. The specific investment cost is € 1675 per kW, including a high voltage cable of € 250/kW (Lako, 2002). The wind farm became fully operational on 11 December 2003 (www.hornsrev.dk, December 2002). The wind farm is expected to produce approximately 600 GWh in an average year.

Table 3.2 *Projected offshore wind farms in Denmark*

| Project | Location | Capacity | Commissioning date |
|---|---|---|---|
| Frederikshavn | Kattegat | 11 MW (4 turbines, 3 types) | Dec. 2002 - June 2003 |
| Nysted | Rødsand (Baltic Sea) | 158.4 MW (72 × 2.2 MW) | October 2003 |
| Laesø | Kattegat | 160 MW | Unknown |
| Omø Stålgrunde | Baltic Sea | 160 MW | Unknown |
| Gedser Rev | Baltic Sea | 160 MW | Unknown |
| Total projected | | 649 MW | |

*Frederikshavn*

The offshore farm near Frederikshavn consists of four turbines of different manufacturers: two turbines will be Vestas V 90, one will be a Nordex N90 and one a Bonus 2.3 MW (WSH 2002). One of the four turbines (a Vestas-V90-3MW) will have an innovative 'bucket foundation', to be used for the first time. The 135 tonnes foundation has the shape of an upturned bucket, which is sucked into the seabed by means of vacuum. The wind turbine was placed on the foundation by the end of 2002. The remaining three wind turbines are placed on traditional foundations and are expected to operate by June 2003 (www.hornsrev.dk).

*Samsø*

The island of Samsø is the official Danish Renewable Energy Island, which should provide in its own energy needs by means of renewable energy. This should be achieved by the year 2008. The offshore wind farm has been erected to supply electricity. It is located 3.5 km south of the island, at Paludans Flak. An amount of 10 turbines of 2.3 MW have a total capacity of 23 MW and will generate approximately 78 GWh per year. The opening of the Samsø wind farm took place in February 2003. (WSH, 2002; www.samsohavvind.dk, April 2002)

*Nysted*

Nysted offshore wind farm at Rødsand is located about 10 km south of Nysted and 13 km west of Gedser. It is being constructed in the period 2002 - October 2003. The park consists of 72 turbines of 2.2 MW with a hub height of 70m. The total capacity is 158.4 MW and the expected production amounts to 500 GWh (WSH, 2002; www.nystedhavmoellepark.dk).

The fate of the three remaining wind farms of the 1998 Plan of Action, the Laesø, Omø Stål-grunde and Gedser Rev projects has been clouded for some time. Recently, the Danish Ministry of Economic and Business Affairs proposed rules for an offshore tender system. To date, this is all the information that is currently available on these wind farms, besides general information and conditions for tendering parties (WPM, 2002a; www.ens.dk/graphics/publikationer/ forsyn-ing/udbudsprocedure_havvindmoeller.pdf, February 2003).

# 4. GERMANY

In a strategy paper of the German government (BMU, 2002) the future wind power potential is estimated as 20,000 to 25,000 MW in the year 2030. This concerns the long-term potential. In the same paper, the cumulative amount of requests has been listed, which are known until now. These requests can be divided into North Sea, for which 22 wind farms have been announced, and Baltic Sea, for which 7 wind farms have been announced. Until the year 2006, this would mean an installed capacity of approximately 5000 MW in the North Sea and approximately 1500 MW in the Baltic Sea.

However, no detailed information is available on most of the wind parks. Table 4.1 lists the parks for which a time horizon and a planning scheme are available. According to the figures mentioned above, for less than 25% of the total projected capacity of 6.5 GW a time schedule was released.

Table 4.1 *Firmly planned offshore wind farms in Germany (five wind farms (partially) to be realised until the end of 2005 (IWR, 2002; Henderson, 2002 and internet sources)*

| Name | Total Capacity [MW] | Projected until 2005 [MW] | Time horizon |
|---|---|---|---|
| *North Sea (EEZ)* | | | |
| Borkum Riffgrund-West[4] | 1800 | 231 | 2004-2005 |
| Dan-Tysk[5] | 1500 | 400 | 2005 |
| Meerwind[6] | 819 | 105 | 2004 |
| Sandbank 24[7] | 4905 | 360 - 432 | 2005 |
| *Baltic Sea (EEZ)* | | | |
| Kriegers Flak[8] | 295 | 295 | 2004-2005 |
| Projected until 2005 | | 1391 - 1463 | |

The projects mentioned in Table 4.1 are the only ones that will be taken into account for the inventory until the year 2006, as presented in Chapter 13: Meerwind Phase 1, Kriegers Flak Phase 1 and 2, Borkum Riffgrund-West Phase 1, Dan-Tysk Phase 1 and Sandbank 24 Phase 1, totalling approximately 1.4 GW by the end of the year 2005.

Depending on the locations of the planned projects, a different authorising body applies. For the Exclusive Economic Zone (EEZ), the issuing body is Bundesamt für Seeschifffahrt und Hydrographie (BSH), while for projects within the 12-mile zone local authorities are important (Landes- und Bezirksregierungen). The overview presented in Table 4.2 is based on a number of literature sources.

[4] Project by EnergieKontor AG. The first phase is projected for the years 2004-2005, and comprises 77 (of in total 458) turbines of 3 MW (www.ofw-online.de, December 2002) (www.boxer99.de, June 2003).

[5] Projected by GEO mbH, first phase 400 MW (80 × 5 MW) in the year 2005 (www.ofw-online.de, December 2002).

[6] Projected by Windland Energieerzeugung GmbH. Phase 1 of 30 × 3.5 MW is projected for 2004. In total, 270 turbines are planned, of which 234 in the EEZ. (www.ofw-online.de, December 2002).

[7] First phase of 120 turbines of 3 or 3.6 MW (www.sandbank24.de).

[8] Projected by Offshore Ostsee Wind AG. Phase 1 consists of 40 turbines of 3 MW in the year 2004 and 35 turbines of 5 MW in the year 2005. (www.ofw-online.de, December 2002).

Table 4.2 *German wind farms in the planning phase*[1]

| Name | Capacity [MW] | Investment [€/kW] | Time horizon |
|---|---|---|---|
| *North Sea (EEZ)* | | | |
| Amrumbank | 1250 | | |
| Amrumbank West | max. 288 | | |
| Borkum Riffgrund | 840 | | |
| Borkum West[9] | 1040 | | |
| Borkum IV | 400 | | |
| Butendiek | 240 | 1667[10] | |
| North Sea Wind power | 1210 | | |
| Weiße Bank[11] | 600 | | |
| Uthland[12] | 400 | | |
| Forseti[13] | | | |
| *North Sea (within 12 miles zone)* | | | |
| Dollart | 9 | | |
| Nordergründe[14] | > 200 | | |
| Offshore Helgoland | 200 | | |
| Riffgat | 135 | | |
| Schleswig-Holstein Nordsee | 800-1000 | | |
| Wilhelmshaven | 4,5 | | |
| *Baltic Sea (EEZ)* | | | |
| Adlergrund[15] | 790 | | |
| Arkona-Becken Südost | 945 | | |
| Beltsee | 415 | | |
| Pommersche Bucht | 1000 | | |
| *Baltic Sea (within 12 miles zone)* | | | |
| Pilotprojekt Mecklenburg-Vorpommern | Appr. 40 | | |
| Sky 2000[16] | 100-150 | | |
| Total projected | 15412 - 15662 or more | | |

[1] The overview has been taken from (IWR, 2002; Henderson, 2002) and Internet sources

[9] First phase 60 MW (12 turbines), later totalling to 208 turbines (www.ofw-online.de, December 2002).
[10] Total investment € 400 million (www.butendiek.de, December 2002).
[11] Projected by Energiekontor AG (www.ofw-online.de, April 2003).
[12] Projected by Gesellschaft für Energie und Oekologie mbH (www.ofw-online.de, December 2002).
[13] Projected by Prokon Nord Energiesysteme GmbH, planned in 11 phases, 1st phase projected for 2010-2015, the last phase projected for 2020-2025. In total, an amount of 1750 wind turbines are projected, of which the capacity is expected to increase during the installation period: 5 MW in the year 2010, until 10 MW per wind turbine from the year 2020 (www.ofw-online.de, December 2002).
[14] Projected by Energiekontor AG (www.ofw-online.de, December 2002).
[15] Projected by Umweltkontor (www.ofw-online.de, December 2002).
[16] Initially, SHOW-VG mbH planned a 100 MW (64 × 1.5 MW) wind farm inside the 12-mile zone, but this has been cancelled for ecological reasons and visual intrusion from the coast. Now, a different location has been chosen, for which 50 turbines of 2 to 3 MW are projected (www.ofw-online.de, December 2002).


Figure 4.1 *Offshore wind power parks projected in German waters: the North Sea on the left, and the Baltic sea on the right*[17]

[17] Picture from www.solarenergie.com/solarzeitung/windenergie/Offshore7-02.html.

# 5. IRELAND

The offshore wind potential of the Republic of Ireland (RoI) is considerable. In a report assessing the technical offshore wind potential (Kirk McClure Morton, 2000), an estimate has been made as a function of maximum water depth and distance to shore. As an example, the area available with a maximum water depth of 20 m and a distance to shore larger than 5 km is estimated at 768 $km^2$ for RoI and 47 $km^2$ for Northern Ireland (NI)[18,19]. In this study, the investment costs are estimated between 1362 and 1750 €/kW, including commissioning and grid connection, depending on location and design.

The majority of the potential mentioned above is located at the east and southeast of the island. At present, 11 consortia have been awarded licences to investigate the suitability of sites for offshore wind energy in Ireland. Some of these applications have been withdrawn and some licences have been refused. Another 24 applications are currently being processed[20]. Table 5.2 lists the projects that are currently known (IWEA, 2003). Based on information available from developers, the combined capacity may be as high as 2000 MW (Garrad Hassan, 2002).

The first construction authorisation has been approved in the beginning of 2002 for the Arklow Bank project in the Irish Sea, consisting of approximately two hundred turbines with a cumulative capacity of 520 MW (www.airtricity.net, December 2002). Construction is planned in four phases, of which the last is projected to be finalised by the end of 2006. Table 5.1 lists the consecutive stages (Garrad Hassan, 2002).

Table 5.1 *Timetable for Aitricity's Arklow Bank offshore wind farm (Garrad Hassan, 2002)*

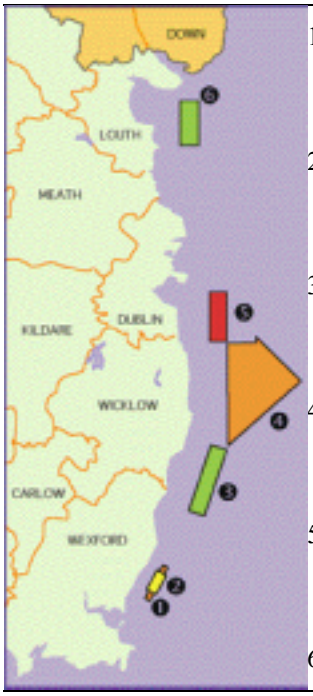
| Stage | Capacity [MW] | Commissioned by |
|---|---|---|
| 1 | 60 | 1 December 2003 |
| 2 | 60 | 1 December 2004 |
| 3 | 160 | 1 December 2005 |
| 4 | 240 | 1 December 2006 |
| Total | 520 | |

[18] In the report a conversion rate for electricity production has been proposed assuming 1.65 MW and 3.0 MW turbines at 500 m spacing. This exercise yields an energy range of 10.5 to 18.4 TWh for RoI and 0.6 to 1.1 TWh for NI.

[19] Note that these numbers refer to the *technical potential*.

[20] This number includes expressions of interest on other sites that currently hold a foreshore licence. There are three expressions of interest outside of Irish territorial waters (IWEA, 2003).

Table 5.2 *Licences awarded by the Department of Marine to investigate the suitability of sites for offshore wind energy in Ireland (IWEA, 2003)*

| Plan of Irish East coast | Number | Consortium | Area | Licence Status | Capacity |
|---|---|---|---|---|---|
|  | 1 | Harland & Wolff Licences Ltd | Blackwater Bank | 2nd Rights | Unknown |
| | 2 | Wind Farm Developments Ltd | Blackwater Bank | 1st Rights | Unknown |
| | 3 | Sure Partners Ltd | Arklow Bank | 1st Rights | 520 MW |
| | 4 | Harland & Wolff Licences Ltd | Codling & Greater Codling Bank | 1st Rights | Unknown |
| | 5 | Kish Consortium | Bray Bank<br>Kish Bank | 1st Rights | Unknown |
| | 6 | Sure Partners Ltd | Dundalk Bay | 1st Rights | Unknown |

# 6. THE NETHERLANDS

An overview of realised projects in the Netherlands is presented in Table 6.1, projected wind farms have been listed in Table 6.2.

In the Netherlands two projects are known at the moment. To begin with, the Nearshore Wind Park (NSW) of the Shell/Nuon consortium NoordzeeWind, a demonstration project of 99 MW near Egmond aan Zee that has been further delayed from 2003 to 2004 at the earliest, due to legislative procedures. The wind farm has been authorised under the condition that extended monitoring and evaluation programmes are being performed. Moreover, the NSW has to be entirely dismantled after 20 years of operation.

The second wind farm, the E-connection Q7-WP wind farm of 120 MW has also been delayed to 2004. This delay is due to uncertainty about government policy during the year 2002. In the year 1999, E-connection submitted other requests for offshore wind farms. The earlier announced Q4-WP of another 120 MW has been withdrawn in order to concentrate on one single location. This has been decided in consultation with the Ministry of Transport, Public Works and Water management. The name Q7 refers to the name of block Q7 of the Dutch Continental Shelf (www.e-connection.nl, December 2002).

More details about the two wind farm characteristics can be found in Table 6.3.

Besides the cancellation of the Q4 wind farm, previous publications often mentioned a 300 MW nearshore wind farm along the Afsluitdijk, between the IJsselmeer and the Waddenzee. The Waddenzee is a precious nature reserve and activities in this area must meet requirements as defined in the nature conservation law and the European Bird and Habitat Directive. In the year 2002, it was politically decided not to develop wind power in this region, because of the impact on the preservation of the open landscape.

Table 6.1 *Realised offshore wind projects in the Netherlands*

| Project | Location | Power | Commissioning date |
|---|---|---|---|
| Lely | IJsselmeer | 2 MW (4 × 500 kW) | 1994 |
| Dronten | IJsselmeer | 17 MW (28 × 600 kW) | 1996 |
| Total realised | | 19 MW | |

Table 6.2 *Offshore wind plans in the Netherlands*

| Project | Location | Power | Commissioning date |
|---|---|---|---|
| NSW | North Sea | 99 MW (36 × 2.75 MW) | 2004 |
| Q7-WP | North Sea | 120 MW (60 × 2 MW) | 2004 |
| Total projected | | 219 MW | |

Table 6.3 *Overview of wind farm characteristics for the two main Dutch offshore wind farms (E-connection, 2002; Olthoff, 2002; PKB NSW, 2000)*

| | Q7-WP | NSW |
|---|---|---|
| Capacity | 120 MW[21] | 99 MW[22] |
| Turbines | 60 × 2 MW | 36 × 2.75 MW |
| Tower height | 57 m above sea level | 60, 70 or 80 m above sea level |
| Expected average net output | 435 GWh per year | 300 GWh per year |
| Investment | 2250 €/kW [23] | 2020 €/kW [24] |
| Distance from shore | 23 km off IJmuiden | 10 km off Egmond aan Zee |
| Water depth | 20 to 25 m | < 15 m |
| Development, engineering, construction and start-up | Vestas - Nederland Windtechnologie, Smit Transport & Heavy Lift, Jan de Nul, Fabricom Oil & Gas and ABB | Noordzeewind Consortium, (Shell and Nuon) |

[21] The turbines are placed in rows parallel to the radar beam of the harbour radar station of IJmuiden. Spacing between the wind turbines is approximately 550 meters.
[22] Three distances to shore and distances between turbines are still under consideration
[23] Total estimated investment costs amount to € 270 million (Volkskrant, 3 April 2003)
[24] Total estimated investment costs amount to € 200 million (Ensoc Weekly, 2002)

# 7. SWEDEN

The first Swedish turbine installed at sea is at Nogersund, a few hundred meters outside the harbour. It is only one turbine of 220 kW, placed on a three-legged platform, commissioned in the year 1990. The project was considered very expensive, and the turbine has been decommissioned (WSH, 2002; Wind and Sea, 2001). The projects that are still in operation or yet to be commissioned are described below (Table 7.1 for realised projects, Table 7.2 for offshore wind plans).

Table 7.1 *Realised offshore wind projects in Sweden*

| Project | Location | Power | Investment [€/kW] | Commissioning date |
|---|---|---|---|---|
| Bockstigen | Gotland | 2.8 MW (5 × 550 kW) | 1700 | 1998 |
| Utgrunden | Kalmarsund | 10.5 MW (7 × 1.5 MW) | 1700 | 2000 |
| Yttre Stengrund | Blekinge | 10 MW (5 × 2 MW) | 1700 | 2001 |
| Total realised | | 23.3 MW | | |

*Bockstigen*

In 1998, the first offshore wind farm in Sweden, the 2.5 MW (5 × 500 kW) wind farm Bockstigen, 4 km from Gotland in 6 m deep water was commissioned. The specific investment cost amounts to approximately € 1,700/kW (Lako, 2002).

*Utgrunden*

The second nearshore wind farm in Sweden - commissioned in 2000 - is the 10 MW (7 × 1.43 MW) wind farm Utgrunden, located near Öland in Kalmarsund where the water is 7-10 m deep and the wind speed is 8.5 m/s. The specific investment cost is € 1,700/kW (Lako, 2002).

*Yttre Stengrund*

In 2001, a third 7.5 MW (5 × 1.5 MW) nearshore wind farm called Yttre Stengrund was commissioned. Yttre Stengrund has roughly the same specific investment cost as Utgrunden (approximately € 1,700/kW) (Lako, 2002).

Table 7.2 *Offshore wind plans for Sweden*

| Project | Location | Power | Commissioning date |
|---|---|---|---|
| Klasarden | Gotland | 42 MW | 2004 |
| Utgrunden II | Kalmarsund | 72 MW (24 × 3 MW) | 2004[25] |
| Total | | 114 MW | |

*Klasarden*

At Klasarden, in Gotland, a 44 MW (16 × 2.75 MW) wind farm is projected for the year 2004. The expected annual electricity production is 120 GWh. The wind farm is planned 1.5 km off the shore, and the water depth varies from 7 to 11 m (WSH, May 2003).

*Utgrunden II*

The previously mentioned Utgrunden wind farm is projected to have an extension of 72 MW (24 × 3 MW): Utgrunden II. The expected annual output is 240 GWh and the installation of the wind farm is projected for the year 2004 (www.airicole.com, June 2003).

[25] For Utgrunden II, *installation* is expected for 2004, not commissioning.

Other wind farms that have been mentioned in older publications, but of which no recent information is available, are located in Öresund near Landskrona (20 × 3.5 MW) and on the Lillgrund Bank near Malmö (48 MW). These have not been taken into consideration in the overview. An overview of possible projects for which precondition investigations[26] are under way can be found on www.airicole.com (June 2003).

[26] All in all, an additional 1.7 GW is under study, of which the Midsjöbanken project (1.1 GW) is the most ambitious

# 8. UNITED KINGDOM

*England and Wales*

England and Wales have one of the largest offshore potentials in Europe and offshore development is supported indeed. The Crown Estate, as landowner of the seabed out to the 12 nautical mile territorial limit, plays an important role in the development of the offshore wind industry by leasing areas of seabed for installation of turbines.

The first offshore wind farm in the UK put into operation was the 4 MW (2 × 2 MW) Blyth wind farm, commissioned in December 2000. This was the first project in the North Sea. The total investment costs amounted to £ 4 million (Power-Technology, 2003).

In December 2000, a Round was announced by the Crown Estate, in order to assess the interest of wind power developers. An overview of sites and companies that applied is presented in Table 8.1. One of the requirements of the Crown Estate (for Round One) is the maximum amount of 30 turbines and a minimum installed capacity of 20 MW. As can be seen from the table, almost all players apply for the maximum amount of turbines. The total park size thus depends on the turbine size, which ranges from 2 to 3.6 MW according to the plans.

Today, at least 2 GW of projects is in the planning phase. Although not sure yet, the 60 MW wind farm North Hoyle on the coast of Wales could be realised in 2003 (www.natwind power.co.uk/northhoyle/progress.htm, June 2003). The realisation of Scroby Sands, a 60 MW wind farm near Great Yarmouth, is projected for 2003, but it is uncertain whether this will be attained. The project is lead by Powergen Renewables and Vestas, who were also involved in the first offshore two turbine pilot project at Blyth Offshore. For most of the sites, no additional information is available.

*Scotland and Northern Ireland*

For Scotland, the only offshore wind farm that is projected is Moray Firth to be realised by Talisman Energy, with a projected capacity of 500 MW (news.bbc.co.uk/1/hi/scotland/ 2042867.stm, 23 December 2002). Tunes Plateau, North of Ulster, is a possible wind farm of 150 to 250 MW. More information about the consortia can be found on www.crownestate.co.uk.

Table 8.1 *Wind farms in the planning phase for the UK (WPM, 2002b)*

| Name | Capacity [MW] | Status |
|---|---|---|
| Blyth | 4 | Realised |
| Solway Firth, Cumbria | 180 | Applied for |
| Barrow, Cumbria | 108 | Applied for |
| Shell Flat, Lancashire | 60-90 | Site studies[27] |
| Southport, Lancashire | - | Cancelled[28] |
| Burbo, Merseyside | 60+ | Site studies |
| North Hoyle, North Wales | 60 | Granted[29] |
| Rhyl Flats, North Wales | 60+ | Applied for[30] |
| Scarweather Sands, South Wales | 60+ | Site studies |
| Kentish Flats, Thames Estuary | 126 | Applied for[31] |
| Gunfleet Sands, Essex | | Site studies[32] |
| Scroby Sands, Norfolk | 76 | Granted[33] |
| Cromer, Norfolk | < 100 | Site studies[34] |
| Lynn, Lincolnshire | < 90 | Applied for[35] |
| Inner Dowsing, Lincolnshire | 60-90 | Applied for |
| Teesside Hartlepool | 60+ | Site studies |
| Tunes Plateau, Northern Ireland | 150-250 | Site studies |
| Moray Firth, Scotland | 500 | Site studies |
| Total realised | 4 | |
| Total projected | 1750 - 1910 | |

[27] Projects planned by Shell Renewables (60+ MW), Elsam (60+ MW) and Scottishpower (60-90 MW)
[28] EnergieKontor decided to withdraw itself for the moment from UK offshore development in order to concentrate resources on German offshore Projects.
[29] Planned are 30 wind turbines totalling 60 MW, projected for the end of the year 2003 (www.natwind power.co.uk/northhoyle/progress.htm, June 2003)
[30] 30 wind turbines with an output equivalent to the electricity required by around 60,000 houses (www.offshorewindfarms.co.uk)
[31] 90MW , to be completed by the autumn of 2004 to spring 2005 (www.offshorewindfarms.co.uk)
[32] 108MW (30 × 3.6 MW) , will supply electricity for approximately 85,000 homes (www.offshorewindfarms.co.uk)
[33] 38× 2 MW, approximately 52,000 homes (www.offshorewindfarms.co.uk)
[34] 30 turbines totalling 100 MW equivalent supply of 85,000 homes (www.offshorewindfarms.co.uk)
[35] 30 turbines generating annually for over 60,000 homes. Investment of £90 million and construction start in 2004. (www.offshorewindfarms.co.uk)

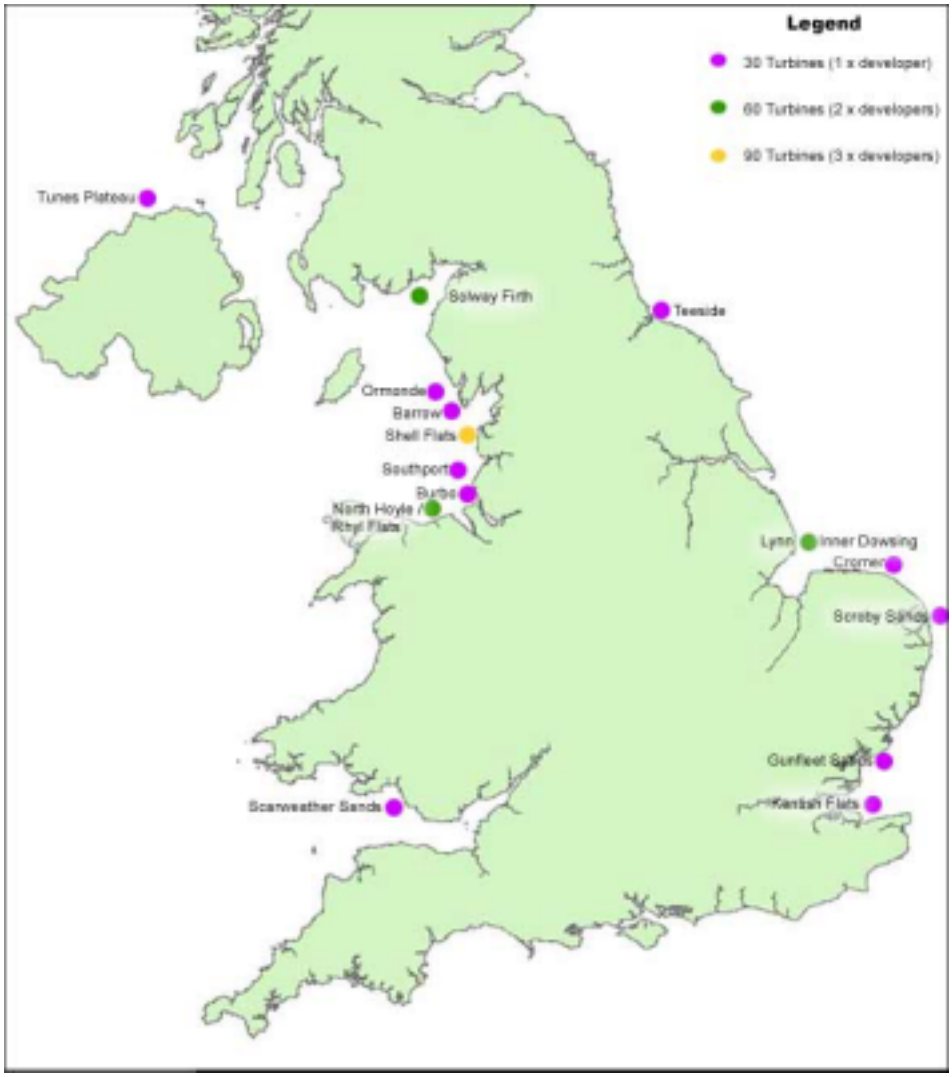



Figure 8.1 *Offshore wind farms in the planning phase for Great Britain (www.crownestate.co.uk, December 2003)*

# 9. OTHER COUNTRIES

## 9.1 Finland

Four offshore wind farms are planned near Helsinki. Each wind farm is projected to have 15 to 20 turbines of 3 MW each. The development of these wind farms would be part of town development plans. A critical issue will be whether government support will be granted (De Vries, 2002).

Table 9.1 *Offshore wind farms in Finland*

| Project | Location | Capacity | Commissioning date |
|---|---|---|---|
| Helsinki | Baltic Sea | Four wind farms of in total 180 to 240 MW (15 to 20 × 3 MW) | Unknown |

## 9.2 France

In the requirements to qualify for the feed-in tariff the size of a wind farm is limited to 12 MW, which is rather small for offshore wind power. In combination with the large, and still underdeveloped onshore potential for wind power, this does not really encourage the development of offshore projects. The only known 'offshore project' concerns one 1.5 MW wind turbine, planned 70 meter off the coast, but this is intended for testing rather than for large-scale production of electricity. This project is expected for the year 2003, and will be located at La Rochelle. De Vries (2002) mentions a 100 MW park at Ile de Croix, South of Bretagne, which would be projected by Shell.

Table 9.2 *Offshore wind in France*

| Project | Location | Capacity | Commissioning date |
|---|---|---|---|
| La Rochelle | La Rochelle | 1.5 MW | 2003 |
| Shell | Ile de Croix | 100 MW | Unknown |

## 9.3 Greece

According to De Vries (2002) EnergieKontor AG acquired several offshore locations in Greece. (EnergieKontor, 2002) confirms that for the Porto Lagos location a local wind survey is being undertaken. This project is thus in an early stage of the planning procedure.

## 9.4 Poland

The first Polish offshore wind farm is projected in the region of Bialogora, near the town of Słupsk, totalling 122 to 183 MW, consisting of 61 wind turbines (of each 2 to 3 MW). Start of installation is expected for the beginning of the year 2004. Design is from the German PT&T Technology (P&T, 2002).

Table 9.3 *Offshore wind plans for Poland*

| Project | Location | Capacity | Commissioning date |
|---|---|---|---|
| Słupsk | Baltic Sea | 122 - 183 MW | 2004 |

## 9.5 Spain

A scoping study for offshore wind in the South of Spain, particularly for the Atlantic coast near Cadiz, has been performed by the KEA-NEK Engineering Group. The wind farm at Cabo de Trafalgar (250 MW, to be installed in 2004-2005) is to be developed in two phases and is located approximately 20 km off the Spanish coast. The total investment is expected to be CDN $ 550 million (KEA, 2002).

Table 9.4 *Offshore wind plans for Spain*

| Project | Location | Capacity | Investment [CDN $/kW] | Commissioning date |
|---|---|---|---|---|
| Cabo de Trafalgar | Atlantic Ocean | 250 MW | 2200 | 2004 - 2005 |

## 9.6 Italy, Norway and Portugal

For Italy, Norway and Portugal no offshore wind projects are known.

## 9.7 Rest of the world

Europe is leading in the realisation of offshore projects. However, the American continent and Japan are also planning offshore wind activities. In British Columbia on the Canadian Westcoast, the 700 MW Nai Kun is planned by ABB and Uniterre Resource, which is to be built during the period 2004-2007. In the United States of America, a project is planned near Cape Cod, Boston with a capacity of 420 MW at an investment cost of minimal US$ 600 million. In Japan, an assessment is being done by the city of Tokyo to build 10 turbines offshore.

As offshore wind power is a sector with fast developments, the number of announced projects is growing very fast. For the United States of America, an inventory of possible sites yielded an amount of 9 GW wind power, and is presented by Winergy (www.winergyllc.com, June 2003). An overview of these locations is given in Table 9.6.

Table 9.5 *Offshore wind plans for the rest of the world*

| Project | Location | Capacity | Investment [US$/kW] | Commissioning date |
|---|---|---|---|---|
| Nai Kun | Canadian Westcoast | 700 MW (350 × 2 MW) | | 2005 - 2007 |
| Cape Cod | Boston, USA | 420 MW (170 × 2.47 MW | 1429 | Unknown |

Table 9.6 *Inventory of possible offshore sites in the USA as presented by Winergy (www.winergyllc.com, June 2003)*

| Location | Capacity (indicative) [MW] | Farm size (indicative) [MW] |
|---|---|---|
| Jones Beach | 241 | (67 x 3.6 ) |
| Plum Island | 12 | (6 x 2 ) |
| Davis Bank | 749 | (208 x 3.6 ) |
| Asbury Park | 353 | (98 x 3.6 ) |
| Smith Island | 796 | (221 x 3.6 ) |
| Great Egg | 439 | (122 x 3.6 ) |
| Nantucket 1 | 832 | (231 x 3.6 ) |
| Nantucket 2 | 763 | (212 x 3.6 ) |
| Isle Of Wight | 1267 | (352 x 3.6 ) |
| Indian River | 1102 | (306 x 3.6 ) |
| Smith Point | 205 | (57 x 3.6 ) |
| Five Fathom Bank 2 | 686 | (196 x 3.5 ) |
| Five Fathom Bank 3 | 965 | (268 x 3.6 ) |
| Fire Island | 227 | (63 x 3.6 ) |
| Hampton | 295 | (82 x 3.6 ) |
| Total | 8932 | |

# 10. EVALUATION OF OFFSHORE WIND IN EUROPE

At present the offshore wind power market is growing very fast. The shockwise addition of capacity in the years 2000 (Middelgrunden, DK) and 2002 (Horns Rev, DK) cause large annual growth percentages. Considering the whole period 1991-2002, an average annual capacity growth of 43% can be observed. The capacities have been displayed in Figure 10.1.

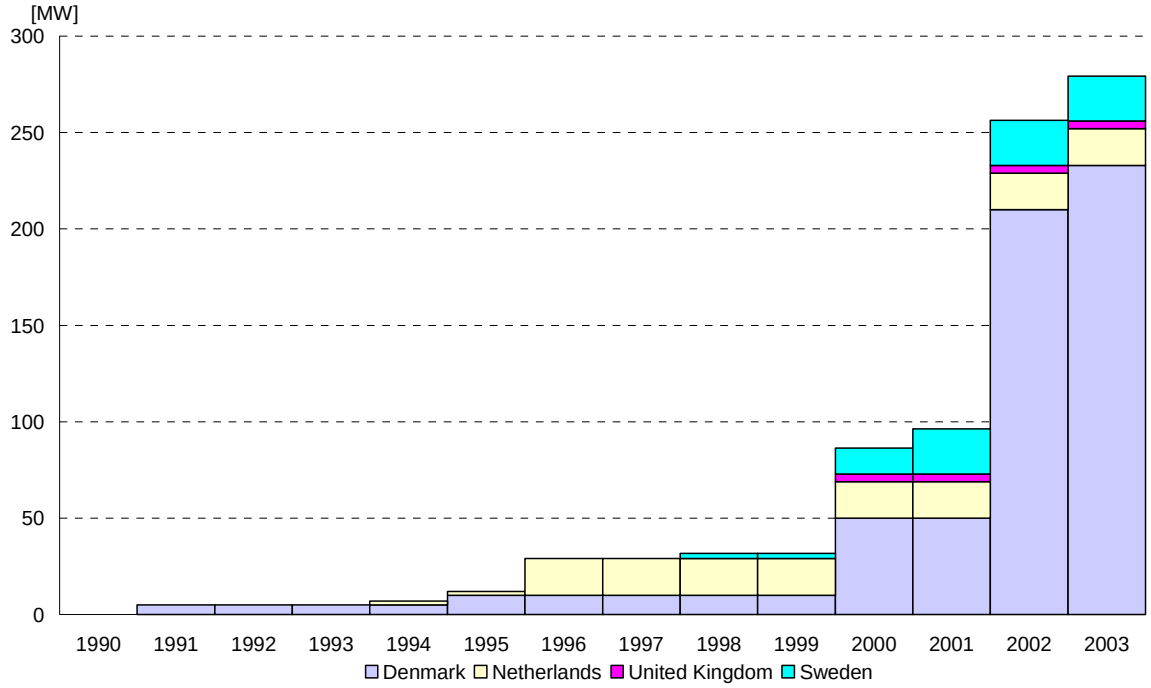



Figure 10.1 *Realised offshore wind power until February 2003*

Considering the expected annual growth based on the projections listed in the previous chapters, the installed capacity by the year 2006 can amount to 3.2 GW to 3.4 GW. This comprises only the wind farms whose projections also mentioned a time schedule. From the previous chapters it can be seen that for many projects no time schedule has been published. Therefore, the capacity in the year 2006 could also be higher than indicated.

Starting with 256 MW by the end of 2002, an installed capacity of 3.3 GW by the end of the year 2006 would mean an *average annual growth* up to 90%. This would mean an increase of capacity with almost a factor 13, and consequently a number of capacity doublings exceeding three[36]. Figure 10.2 indicates these projections until the year 2006.

Summing up all European projects that have been listed in the current report yields a total capacity of 24 to 25 GW. This capacity, however, can only be attained in the long term and is very uncertain. The chronological development in realisations and projections has been listed in more detail in Table 10.1.

[36] An increase of capacity by a factor 12.9 means that the amount of capacity doublings is equal to 3.7 (since $2^{3.7}=12.9$).

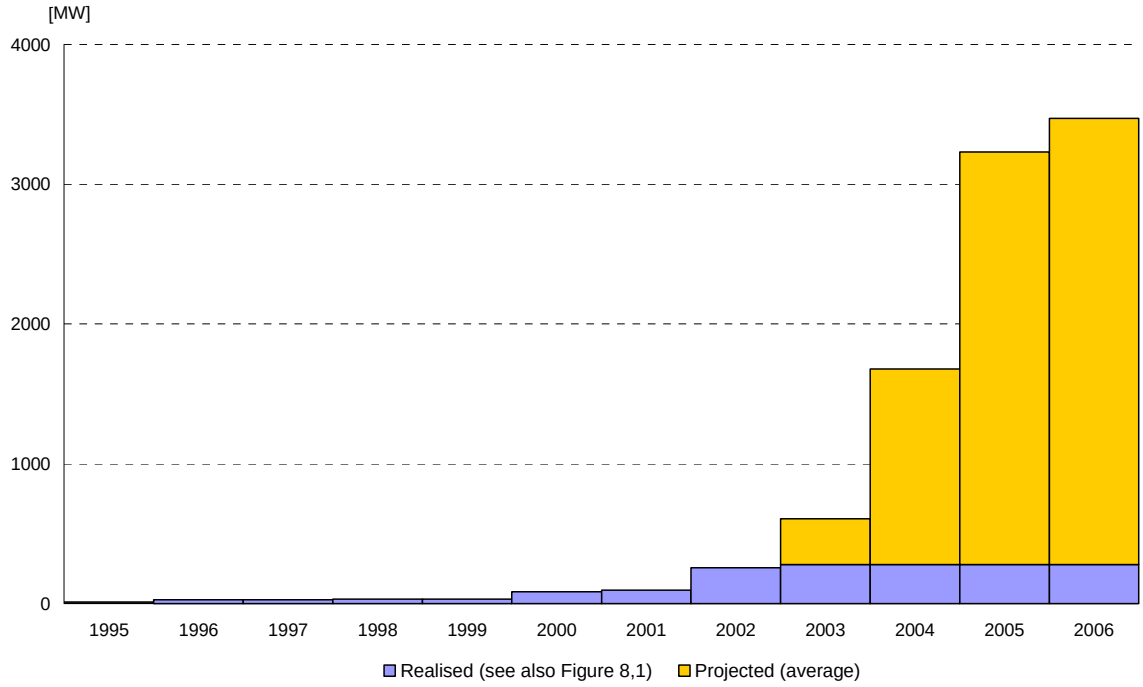



Figure 10.2 *Projections as listed in the previous chapters*
Note: Projects until the year 2006 have been based only on those, for which a time schedule has been available

Table 10.1 *A chronological overview of European offshore wind projects in the past and in future*[37]*. In parentheses, the country names have been indicated*

| Year | Realised | Projected | Average Cumulative installed capacity | |
|---|---|---|---|---|
| 1990 | | | 0 | MW |
| 1991 | Vindeby (DK) | | 5 | MW |
| 1992 | | | 5 | MW |
| 1993 | | | 5 | MW |
| 1994 | Lely (NL) | | 7 | MW |
| 1995 | Tunø Knob (DK) | | 12 | MW |
| 1996 | Dronten (NL) | | 29 | MW |
| 1997 | | | 29 | MW |
| 1998 | Bockstigen (SE) | | 32 | MW |
| 1999 | | | 32 | MW |
| 2000 | Middelgrunden (DK), Utgrunden (SE), Blyth (UK) | | 86 | MW |
| 2001 | Yttre Stengrund (SE) | | 96 | MW |
| 2002 | Horns Rev (DK) | | 256 | MW |
| 2003 | Samsø (DK) | Zeebrugge (BE), Frederikshavn (DK), Nysted (DK), La Rochelle (FR), North Hoyle (UK) | 0.3 | GW |
| 2004 | | Vlakte van de Raan (BE), Meerwind Phase 1 (DE), Kriegers Flak Phase 1 (DE), NSW (NL), Q7-WP (NL), Słupsk (PL), Klasarden Gotland (SE), Utgrunden II (SE) | 1.4 | GW |
| 2005 | | Thornton Bank (BE), Borkum Riffgrund-West Phase 1 (DE), Dan-Tysk Phase 1 (DE), Kriegers Flak Phase 2 (DE), Sandbank 24 Phase 1 (DE), Cabo de Trafalgar (ES) | 3.1 | GW |
| 2006 | | Arklow Bank (IE) | 3.3 | GW |

[37] In most cases, construction works have been planned in a period, for example 2004 – 2006. In such cases, the park is attributed to the last year in the period, in this example 2006.

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