European Commission

General Information

Concerted Action for Offshore Wind Energy Deployment (COD)

WORK PACKAGE 8: GRID ISSUES

5

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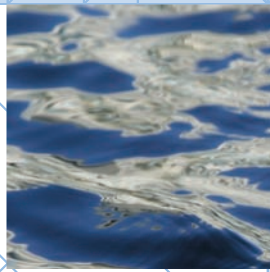

Concerted Action for Offshore Wind Energy Deployment (COD)

WORK PACKAGE 8: GRID ISSUES

Contractant: European Commission, Contract NNE5-2001-00633 (COD)

3E Reference: BWE262

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Date : 4/10/2005

Summary

The objective of the European Concerted Action on Offshore Wind Energy Deployment (COD) is to speed up the responsible deployment of offshore wind energy in the EU by early identification and possibly to remove not explicitly technical barriers: legal, administrative, policy, environmental and grid infrastructure planning issues. The COD project is carried out by eight sea-bordering member states, represented by their energy agencies or delegated third parties. The participating countries are Belgium, Denmark, Germany, Ireland, the Netherlands, Poland, Sweden and the United Kingdom. France has joined the project in 2005 as an observer.

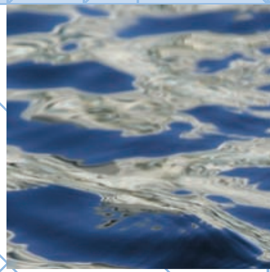
Main points of concern for the connection of offshore wind farms to the national power systems are transmission bottlenecks, power system stability, offshore transmission infrastructures and grid access, pricing and balancing. Moreover the grid integration of offshore wind energy is strongly affected by the possibilities for Trans-European power exchange. In the present report national grid studies from the eight participating countries are reviewed with regard to these issues and their content is collected in a common information base. Further emphasis has been put on the technical and market aspects of Trans European power exchange.

The available information is assessed and conclusions are drawn. These are further elaborated in order to arrive at generalised observations, recommendations for policy makers, and issues that will emerge in the near future.

The main conclusions and recommendations are:

- Grid reinforcements are necessary in order to facilitate the grid connection of offshore wind farms in the future; however, they require very long lead times. High-voltage DC links on shore may be an alternative to new overhead lines.
- In wind transmission grid codes there is a trend towards active control of large wind farms within the boundaries of the legal frameworks. This contributes to grid stability although some contractual issues are still unclear. The capabilities required from large wind farms should be harmonized with TSO-specific set points.
- Common offshore cables bundling several wind farms would be beneficial. Moreover they can become initial nodes of an international offshore grid. Up to now no bundling has taken place.
- Grid access, energy pricing and balancing are interrelated. Concepts to increase the value of wind energy comprise of adapted demand control, back-up generation or storage. Furthermore, good short-term forecasting will increase the value of wind energy on energy markets.
- In order to take advantage of the spatial decorrelation of wind speed, transmission of wind power must be possible over distances comparable to the extensions of meteorological systems. Strong Trans European networks are essential for this purpose, but the economic case for such networks (in comparison to competing options) is not yet clear.

In conclusion, many things need to be done on a technical level in order to integrate large amounts of offshore wind power into our power systems. However, none of these measures is technically unknown. Therefore, the feasibility of integrating large amounts of offshore wind power is mainly a question of finance, and hence based on political decisions and the creation of a favourable framework.



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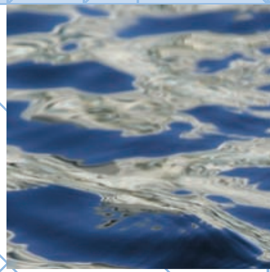


Glossary

To a large extent this glossary is based on definitions given by ETSO or UCTE. To some extent their definitions have been modified for application in the context of this study. Finally, some of the more specific terms have been defined by the authors.

Active power

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

Ancillary services

Ancillary services are services identified as necessary to effect the transmission of electricity.

Apparent power

Apparent power is the product of voltage (in volts) and current (in amperes). It consists of a real component (active power) and an imaginary component (reactive power), usually expressed in kilovolt-amperes (kVA) or megavolt-amperes (MVA).

ARP/PRP – Access responsible party/programme responsible party/balance provider

Electricity market actor which has the responsibility towards the TSO of balancing supply and demand within each settlement period. Typically, energy suppliers either need to be a balance provider themselves or make a respective contract with a balance provider. In some countries imbalance is penalized by the TSO in order to prevent market actors from speculating with balancing power.

Balancing

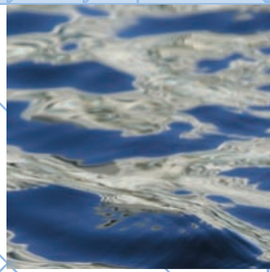
Balancing is the activity of keeping a stationary equilibrium between demand and supply at all time scales in order to ensure a stable operation of the power system. Balancing is done via automatic (primary and in the UCTE also secondary) control and via manual control (by reserve power, demand control and trade).

CHP – Combined heat and power

A plant designed to produce both heat and electricity from a single heat source.

COD

European Concerted Action for Offshore Wind Energy Deployment



Control area

A control area is a coherent part of an interconnected power system (usually coincident with the territory of a company, a country or a geographical area, physically demarcated by the position of points for measurement of the interchanged power and energy to the remaining interconnected network), operated by a single TSO, with physical loads and controllable generation units connected within the control area.

DEWI

Deutsches Wind Energie Institut

EEZ – Exclusive economic zone

The EEZ is an area beyond and adjacent to the territorial sea, extending up to but not beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured and includes, besides the sea-bed and its subsoil, the waters superjacent to the sea-bed.

ETSO

Association of European Transmission System Operators

Exlusive zone

In the given context exclusive zones are areas of the sea which are available for one specific type of use only. Often the existence of exclusive zones for offshore wind energy implies that all other zones are not available for this use.

GIL – Gas-insulated line

Gas-insulated lines are based on high-voltage cables with a gaseous dielectric.

Grid code

A grid code specifies the technical terms and conditions for access to and use of a power system. With regard to wind energy, grid codes specify the technical requirements for a wind turbine or farm in order to receive access to the power system.

HVAC

High-voltage AC power transmission (AC: alternating current). Three-phase HVAC systems are the classical transmission systems in Europe.

HVDC

High-voltage DC power transmission (DC: direct current). HVDC systems are connected to the classical HVAC system by means of power electronic converters.

NOIS

Nordic Operation Information System. The Nordic balancing market.

Power control, active power control

Here, the term refers to the possibility of controlling the output power of a wind turbine and setting it to a value lower than the maximum power at given wind speed.

Primary control

Automatic reaction of the primary controller of generating sets to a frequency deviation caused by a system disturbance or small variations in production and consumption – also referred to as primary response or momentary reserve.

Reactive power

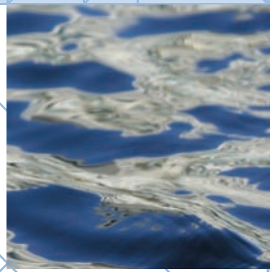
Reactive power is an imaginary component of the apparent power. It is usually expressed in kilo-vars (kVAr) or mega-vars (MVAr). Reactive power is the portion of electricity that establishes and sustains the electric and magnetic fields of alternating-current equipment. Reactive power must be supplied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

RES-E directive

Directive 2001/77/EC of the European Parliament and the Council of 27 September 2001 on the promotion of electricity from renewable energy sources in the internal electricity market, Official Journal of the European Communities, 27 October 2001.

Secondary Control

Instructed action of particular generating sets linked to a control loop in a control area, to move the overall system (frequency and interchange) deviation of the control area toward zero following the delivery of primary control in response to a sudden variation in production or consumption. The term is only applied in the UCTE.



TSO – Transmission System Operator

Transmission System Operators are responsible for the bulk transmission of electric power on the main high voltage electric networks. They guarantee the safe operation and maintenance of the system. In many countries, TSOs are in charge of the development of the grid infrastructure too. In the European Union internal electricity market TSOs must operate independently from other electricity market actors.

UCTE – Union for the Co-ordination of Transmission of Electricity

Among other tasks the UCTE monitors and supervises the development of the UCTE synchronous zone in continental Europe.

Voltage ride through

Capability of a wind turbine to continue supplying power during dips of the grid voltage.

Introduction

The European Concerted Action on Offshore Wind Energy Deployment (COD) wants to speed up the responsible deployment of offshore wind energy in the European Union. The objective is the early identification and possibly the removal of barriers that are not explicitly technical: legal, administrative, policy, environmental and grid infrastructure planning issues.

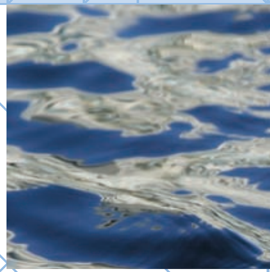
The concerted action is carried out by eight sea-bordering member states, represented by their national energy agencies or delegated third parties. The participating countries are Belgium, Denmark, Germany, Ireland, the Netherlands, Poland, Sweden and the United Kingdom. France has recently joined the COD as an observer.

Barriers affecting the connection of offshore wind farms to the national power systems are one major topic of the COD. Main areas of emphasis are transmission bottlenecks, power system stability and grid codes, offshore cable connections, grid access, energy pricing, balancing and aspects of Trans-European power exchange.

In most of the participating countries, some or all of these subjects have been studied by government bodies or transmission system operators (TSOs). These studies from the eight participating countries have been reviewed with a focus on the relevant grid issues and their content has been collected in the present report. The objectives are on the one hand to describe particularities due to the specific situation in certain countries, and on the other hand to identify characteristic patterns that are visible in all participating countries.

Since the definitions, the kind of available information and available formats are different in each country an open report format has been chosen. The relevant issues are summed up descriptively in a specific section per country rather than in a data base in the narrow sense of the term.

In Chapter 2 we will give an overview of the collected data items. The Chapters 3 to 10 provide a summary of the most important information for each of the participant countries. A survey of key data for all participating countries is provided in Annex 2. An overall analysis of the country-specific situation is carried out in Chapter 11. There, specific obstacles and solution are identified that are common to several countries, e.g., due to their geographical situation or grid structures. The aspects of cross-border exchange of electricity, the technical boundary conditions and the market environment, and the main parameters that effect the grid integration of offshore wind energy are treated in Chapter 12. The report closes with conclusion and recommendations for further action.



Collected Data Items

Grid data from the participating countries had to be collected. The challenge was to make a selection of items significant for offshore wind energy while staying concise and obeying to given constraints in terms of time and budget. This is complicated by the differences of offshore wind energy deployment and grid infrastructures in the participating countries. Therefore, a free format for data collection had been chosen, based on a number of significant items. These items and the respective key data are collected in the survey in Annex II. Data has been collected for the following items:

2.1 Plans and Prospects

This contains the geographical areas where offshore wind farms will most probably be built in the future. The data for installed capacity are partly based on granted licences for exploitation and partly only long-term objectives and not based on existing applications. Accordingly, the time horizon varies from country to country.

2.2 Power System

These contain information about the transmission system in the country, including the TSOs and control areas for which they are responsible, and load and generation data in the country. Installed capacity, minimum and peak loads are necessary to put the projected wind generation capacity in perspective and calculate the penetration depth.

Data for 2002 have been used since these statistics have become widely available for all countries. While most power system data are not changing significantly over the years, it should be noticed that the installed generation capacity from wind power and other renewables in some countries have more than doubled the last three years. Where this has been the case recent figures are specified.

Pumped storage has not been accounted for separately but categorised as hydropower. This is because in terms of the maximum generation capacity in comparison to wind generation capacity the difference is less relevant.

2.3 Offshore Power Injection

This item contains possible injection points for offshore wind energy to the transmission system. In most countries, a limited number of high voltage substations are available at the shore where offshore wind parks of up to several hundreds of megawatts could be connected. As far as this information is publicly available, the best-suited substations have been inventoried and the limit for power injection from offshore wind parks per substation or identified offshore area.

2.4 Grid Issues

Grid issues that are described here are transmission bottlenecks, requirements of the grid code and the national situation concerning balancing of supply and demand.

Bottlenecks for the transmission of power from offshore wind farms typically occur where centres of electricity demand are situated far from the coast. In that case, one or several links between the substation close to the shore and the load centres will have to be reinforced. Such transmission grid reinforcements can be subject to long planning permission and building procedures and delay the development of projected offshore wind farms substantially.

In each country analysed, a Grid Code defines the requirements for the connection of wind farms to the transmission system. More and more the Grid Codes require wind farms above a specific size (some 10s of MW) to participate in power system control. Typically, these requirements may include voltage and frequency control, ride through capabilities in case of voltage dips and provisions for the maximum and minimum change rate of output power. Suggestions for wind farm grid code requirements have also been made by the UCTE [UCTE 04].

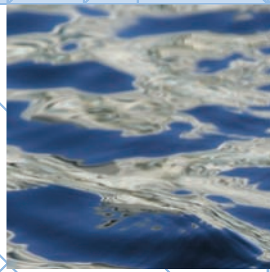
Within a control area, the technical activity of balancing supply and demand is usually the responsibility of the TSO. Markets often require positions to be reconciled within each market trading period (say, for every 15 minute interval). Reconciliation is typically accompanied by financial settlement, with the intention that imbalance costs are attributed to parties whose individual portfolios are out of balance. In some countries, short-term predictions for wind power generations are mandatory in order to facilitate balancing. In others, it is incentivized by virtue of imbalance penalities.

2.5 External Factors

This refers to factors that are not directly related to wind energy but still affecting the connection of offshore wind farms. Examples are transnational flows or cross border exchanges that affect transmission capacities for offshore wind power. In the same way, new transmission lines may affect the transmission capacities available for offshore wind power.

2.6 Offshore Cable

This refers to the cable connection from the wind farm to the substation at the shore. Possibilities for power transmission are high-voltage AC (HVAC) and high-voltage DC (HVDC) either using the classical thyristor inverters or inverters with fast-switching IGBTs. The latter are also known under the trade marks HVDC Plus and HVDC Light.



In some countries, different ways have been considered of landing the cable at the shore. Especially at vulnerable coastlines it is considered to collect the power from several wind farms at one offshore substation in order to cross sensitive areas of seabed only once.

2.7 Connection and Energy Pricing

Generally speaking, connection charges for distributed and decentralized generation connected to the transmission system can be classified shallow or deep, indicating the degree of penetration into the power system up to which the grid connection and necessary reinforcements will be charged to the owner of the distributed resource. Since large offshore wind farms will be connected to the transmission system, their situation is more specific. In some countries, the situation is not yet clear or determined on a per-project base while in others this is defined by law.

Priority access for electricity from renewables to the power system is suggested in Article 7 of the European RES-E directive [RES-E 01]; however, the national implementations can vary in the different countries. Especially, priority access is irrelevant if there is not a suitable economic basis for renewable energy projects. Priority access is one way of providing economic support to renewables projects, but it is not essential and may not, on its own, be sufficient.

2.8 References

[UCTE 04] Wind power in the UCTE interconnected system, Network of Experts in Wind Power, UCTE, 25 November 2004.
http://www.ucte.org/pdf/Publications/2004/Wind_Power_20041125.pdf, accessed Mai 3, 2005.

[RES-E 01] Directive 2001/77/EC of the European Parliament and the Council of 27 September 2001 on the promotion of electricity from renewable energy sources in the internal electricity market, Official Journal of the European Communities, 27 October 2001.

Belgium

3.1 Plans and Prospects

Up to now in Belgium, project developers had to identify potential sites by themselves and apply for a domain concession and an environmental permit [Shaw 02]. Recently, the legislation has been changed and an exclusive zone for offshore wind energy has been assigned. Within this zone, a domain concession should now be relatively easy to obtain. The area of this zone is 270 km2 with a technical potential of about 2.5 GW installed wind power. A recent study by 3E and others [VanH 04] targets 1750 to 2000 MW to be in operation in this zone by 2020, evolving over time as indicated in Figure 3-1.

The exclusive zone for offshore wind energy within the Belgian EEZ is indicated in Figure 3-2.

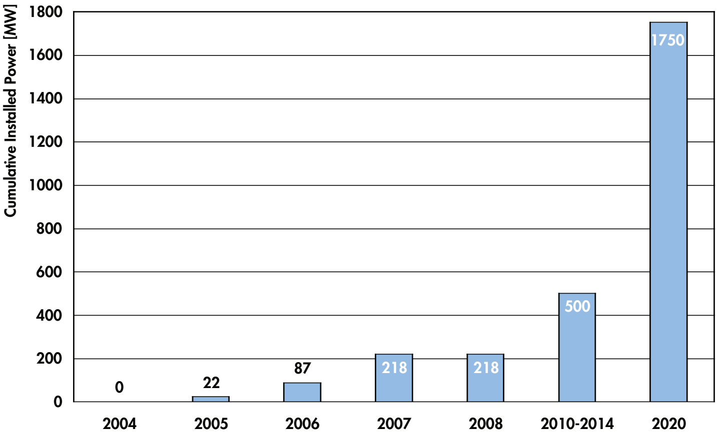


Figure 3-1: Plans and prospects for installed offshore wind power in Belgium [VanH 04]

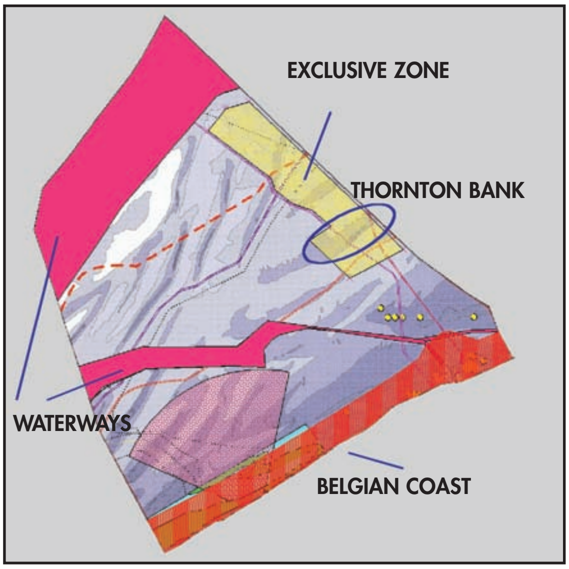
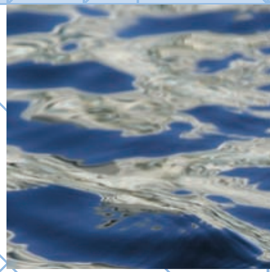


Figure 3-2: Belgian EEZ and designated exclusive zone for offshore wind energy [VanH 04]



3.2 Power System

Table 3-1 gives the installed power generation capacity on Belgian territory by the end of 2002. The overall generation capacity was 15.5 GW. The maximum load in 2002 was 13.7 GW, the minimum load was approximately 6 GW. The final electricity consumption in 2002 was 78.4 TWh [Euro 04, BFE 03].

The installed wind power generation capacity has grown from 30 MW in 2002 to 95 MW in 2004 [EWEA 05].

Table 3-1: Installed power generation capacity in 2002 [Euro 04]

Technology	Nuclear	Thermal	Hydro	Wind	Others	Total
Rated power [GW]	5.76	8.34	1.41	0.03	-	15.54
Percentage	37.1	53.6	9.1	0.2	-	100

In Belgium, all lines above 70 kV are legally considered transmission lines. These lines are operated by the national TSO Elia. The Belgian transmission system is one single control area operated by Elia. It makes part of the UCTE synchronous zone.

3.3 Offshore Power Injection

From the three substations on the Belgian coast Zeebrugge, Slijkens and Koksijde, only those in Zeebrugge and Slijkens are eligible for the connection of offshore wind farms. A new 150 kV connection between Slijkens and Koksijde is currently under construction. This connection will become ready during 2006 and has already been taken into account here.

No 400 kV connections are currently available on the coast (Figure 3-3 and Figure 3-4).

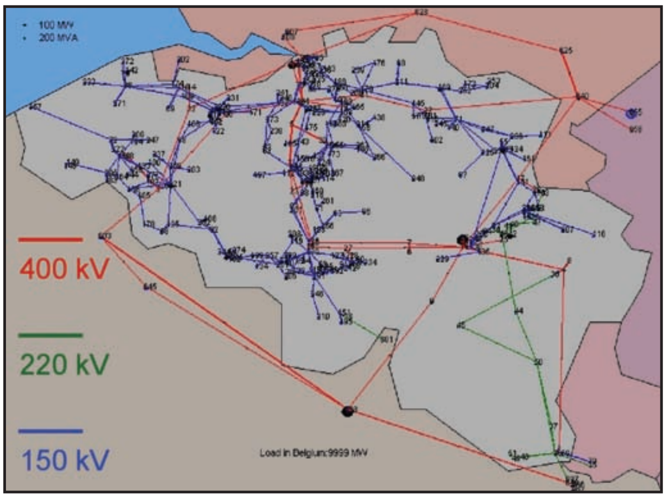


Figure 3-3: National transmission grid [VanR 01]

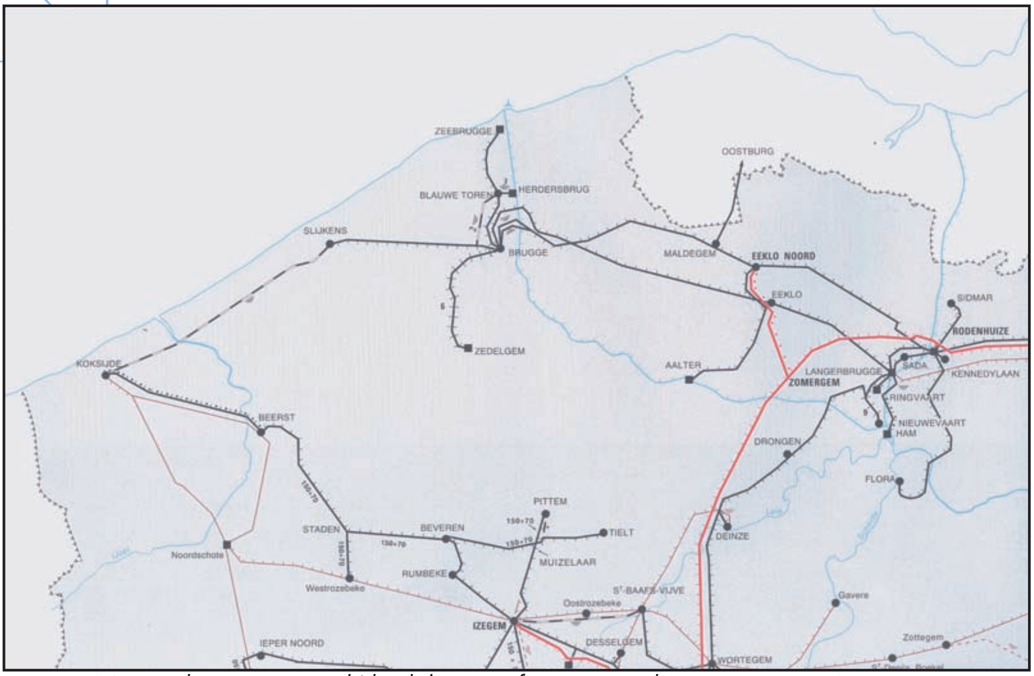


Figure 3-4: National transmission grid (detail showing infrastructure at the coast, source ELIA

Table 3-2: Eligible substations for the grid connection of offshore wind farms [VanH 04]

Substation	Voltage [kV]	export capacity to high voltage
Zeebrugge	150	300 MW to Brugge
Slijkens	150	350 MW to Brugge and Koksijde

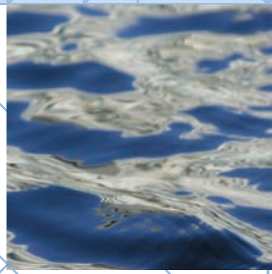
Table 3-3: Zones for offshore wind parks and available export capacity at the eligible substations

Zone	**Prospects**	**Substations**	**Total export capacity**
Belgian exclusive zone for OWE	1750 MW	Zeebrugge, Slijkens	650 MW

3.4 Grid Issues

Transmission Bottlenecks

The export capacity to the high voltage system given in Table 3-2 and Table 3-3 becomes the limiting factor when the consumption in the area around these substations is low. It becomes clear that without further grid extensions 650 MW can be connected at maximum. Note that the given values are indicative values. When a specific offshore project is planned, an orientation study can be ordered



from ELIA where the best option for connecting the wind farm will be identified. ELIA has summarized different options in order to maximize the connectable power in its development plan from September 2003 [ELIA 03].

The C-Power wind farm, which currently is under development on the Thornton Bank with 218 up to 300 MW, will be connected to the substation in Slijkens. Hence, a further project of more than 300 MW can not be connected to the Belgian transmission system unless the connection would be distributed over the two substations.

In order to transport the projected high power from offshore wind farms to the load centres, the 400 kV system will have to be extended to Slijkens or Zeebrugge. In September 2005 the Belgian TSO Elia has to submit a new development plan for the Belgian transmission system, which will cover the extension of the 400 kV system to the coast including an estimate of the costs [Mulp 04].

Grid Connection

General guidelines for the connection of wind farms to the transmission system have not yet been published in Belgium but are currently under development by the TSO [VanR 04]. Moreover the grid code for high voltage is applicable [Bel 02]. The drafted requirements contain the following.

- Common power quality requirements
- Primary control (frequency): not required
- Power control: not required in general; curtailment required in case of specified situations; required power reduction of minimum 10% of installed power per minute
- Reactive power required for wind parks with more than 25 MW
- Disturbances:
- Frequency: < 47.5 Hz, > 52.5 Hz: switch off within 0.2s
- Frequency: between 48 and 48.5 Hz: switch off after 10 min
- Voltage ride through:
  <10%: 0.2 s,
  < 80%: 5 s,
  <50%: 0.7 s

These requirements are less strict than those in Germany and Denmark and it is not expected that requirements in Belgium will become stricter than in these pioneering countries.

A study of the impact of offshore wind energy on the transient stability of the Belgian power system turned out that offshore wind energy would not significantly affect the grid stability long as no more than 1 GW are installed [Soen 03, VanH 04].

Balancing

In the Belgian liberalized electricity market, balancing lies in the responsibility of so-called access responsible parties (ARPs). The ARP is responsible towards the TSO to maintain the quarterly power balance over all its connection points. Each day, the ARP has to submit a schedule for a balanced load profile for the next day. ARPs can trade power on the intraday hub. Deviations from the schedule are penalized by the TSO.

Every market player that wishes to use the Belgian transmission system has to contract an ARP or be ARP itself for its connection points. Typically, ARPs are large suppliers or other market players with the capability to fulfil this task.

As a consequence, the Belgian balancing requirements work as an economic threshold lowering the value of grey electricity from wind energy. For the time being, fluctuating wind energy output does not form a technical barrier to the grid integration of large wind farms. In the longer term, advanced short-term forecasting can be applied in order to take wind power into account for balancing.

3.5 External Factors

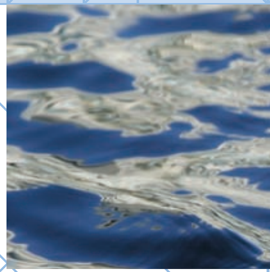
Congestion of transmission lines inside the country may be affected by external factors being

- long-term contracts of Dutch energy suppliers with either Electricité de France (EDF) or Scandinavian generators, affecting the transit through Belgium.
- the future of the Rodenhuize power plant. This will either be shut down or extended. In the first case, transmission capacity on the 400 kV line from Rodenhuize to Heimolen will become available for offshore wind power. In the latter case, the line will have to be extended and additional capacity will become available. This line is often congested today; however, this does not directly affect the power transmission from offshore wind farms.

3.6 Offshore Cable

The C-Power wind farm on the Thornton Bank will be connected by a 150 kV three-phase HVAC cable. The coast line will be crossed by drilling under the dune and passing the cable through this hole. This way the strength and structure of the dunes that are protecting the Belgian coast from the sea will not be affected.

For the long term for the optimal landing of a high number of cables arriving from offshore wind farms no plans have been made yet.



3.7 Connection and Energy Pricing

In Belgium renewables have priority access to the grid. Connection charges for DG are generally shallow [Donk 04].

For the C-Power project on the Thornton Bank, the offshore substation and the cable connection to the Slijkens substation have to be borne by the project developer while any further extensions of the high voltage system are for the TSO. In January 2005 the Belgian government has decided that additionally 1/3 of C-Power's costs for this grid connection with a maximum of 25 million Euro will be borne by the TSO and socialized via the transmission tariff [Sert 04, Min 05].

Whether future offshore projects can receive comparable government support is not yet clear.

Power producers from offshore wind energy can get tradable green certificates. These can be redeemed in order to meet quota obligations for green energy supply in one of the Belgian regions. Alternatively, certificates from offshore wind power can be sold to Elia that has to buy them at a minimum price of €107/MWh. The remaining "brown" value of offshore wind energy depends on market prices.

3.8 Conclusions

The main bottleneck for the large-scale deployment of offshore wind energy in Belgian waters is the transmission capacity of the high voltage grid. In order to accommodate the projected 1750 MW from offshore wind farms in the Belgian transmission system, the 400 kV grid will have to be extended to a coastal substation.

In September 2005 the Belgian TSO Elia has to submit a new development plan for the Belgian transmission system, which will cover the extension of the 400 kV system to the coast.

A number of alternatives may be applicable in order to make the project independent of the lengthy procedures for grid extension. Possibilities may be for example DC transmission links on shore, dynamic line ratings or local energy buffering.

3.9 References

[Bel 02] Koninklijk besluit houdende een technisch reglement voor het beheer van het transmissienet van elektriciteit en de toegang ertoe – 19 December 2002. Belgisch Staatsblad, December 2002.

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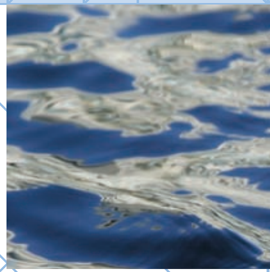


Denmark

4.1 Plans and Prospects

A number of small offshore and near shore wind farms have been in operation in Denmark for several years (Table 4-1). Currently, 427 MW are in operation in Denmark, including the large offshore wind farms of Horns Rev in the North Sea and Rødsand in the Baltic Sea. Second phases for Horns Rev and Rødsand are planned to become operational in 2008. As a long-term objective, the action plan for renewable energy Energi21, set up by the government in 1996, aims at 4 GW of offshore wind farms in 2030 [Mili 96].

In Denmark some areas suited for offshore wind energy have been identified although no areas have been specifically designated to offshore wind energy. The first large projects, Horns Rev and Rødsand are situated in the North Sea west of Jutland and in the Baltic Sea, south of the island of Lolland, respectively (Figure 4-1). The wind farms currently under development will be erected in the same areas and possible near the island of Omø. In the long run, wind farms may also be erected further north in the North Sea, the Kattegat, and the Great Belt.

Table 4-1: Status, plans and prospects for installed offshore wind power in Denmark

Year	2005	2008	2030
Western Denmark	216 MW	416 MW	
			4000 MW
Eastern Denmark	211MW	411 MW	

Figure 4-1: Operational and planned offshore wind farms in Denmark [Lang 05]

4.2 Power System

The Danish power system is split into two sections which make part of different synchronous zones. The transmission system in the western part of Denmark covers the Jutland peninsula and the Islands west of the Great Belt. It makes part of the UCTE synchronous zone with two AC connections to Germany. The transmission system in the eastern part of Denmark covers the islands east of the Great Belt including the largest island Zealand. It makes part of the Nordel synchronous zone with several AC connections over the Øresund to Sweden. In 2005 the former two TSOs Eltra and Elkraft have merged together with the Danish gas TSO and become Energienet.dk. However, this merger does not affect the separate operation of the two synchronous zones.

Table 3-1 gives the installed power generation capacity on Danish territory by the end of 2002. The overall generation capacity was 13.3 GW. The maximum load in Western Denmark in 2002 was 3.68 GW, the minimum load was approximately 1.19 GW. The maximum load in Easteren Denmark was 2.68 GW and the minimum load was 0.83 MW. The final electricity consumption in Denmark in 2002 was 32.7 TWh [Euro 04].

The installed wind power generation capacity has grown from 2.89 GW in 2002 to 3.12 GW in 2004 [EWEA 05].

Table 4-2: Installed power generation capacity in 2002 [Euro 04]

Technology	Nuclear	Thermal	Hydro	Wind	Others	Total
Rated power [GW]	-	10.4	0.01	2.89	-	13.30
Percentage	-	78.2	0.1	21.7	-	100

The system in Western Denmark contains 400 kV and 150 kV lines. It is linked to Sweden and Norway by HVDC and to Germany by HVAC. It is not connected to the system in Eastern Denmark. The system in Eastern Denmark contains 400 kV and 132 kV lines. It is linked by HVDC to Germany. A HVDC link between Eastern and Western Denmark is under consideration.

Beside wind power, Western Denmark also has a high amount of distributed generation by means of combined heat and power (CHP) systems. Therefore, the system in Western Denmark is the transmission system with the largest fraction of decentralized generation in Europe (Table 4-3). Only 46% of the installed generation capacity is cumulated in centralized traditional thermal units.

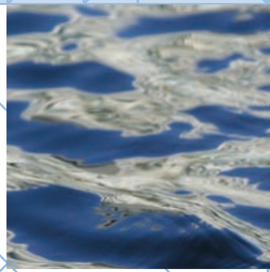


Table 4-3: Installed power generation capacity in January 2004 by size and type [Eltr 04a]

Type	Power [MW]
Power stations connected to grids with voltages > 100kV	3402
Power stations connected to grids with voltages < 100kV	1656
Wind turbines, land-based and onshore	2214
Wind turbines, offshore	160
Total installed capacity	7432

4.3 Offshore Power Injection

In Western Denmark a number of possible connection points are available at the coast. The Horns Rev A wind farm is connected to 150 kV at Karlsgårde. Even larger farms could be connected, for example at the 400 kV substations Idomlund and Endrup, more south in Kassø or up north in Nordjyllandsværket (Figure 4-2).

For the connection of very large wind farms above 500 MW, Energinet.dk proposes a connection to several connection points by means of offshore grids. In the long run, Energinet.dk suggests to study the possibilities for interconnection of Dutch, German and Danish wind farms via an offshore grid and connection to the onshore transmission systems at several injection points in these countries and also in Norway [Eltr 04a, Eltr 04b].

Figure 4-2: Transmission system in Western Denmark (red: 400 kV, black 150 kV, blue: HVDC) [Eltr 04b]

In Eastern Denmark, possible connection points are Radsted, Vestlolland, Stignæsværket, all of them at 132 kV [Elkr 04]. The 132 kV grid in the southern part of Eastern Denmark limits the maximum power injection at these points. No 400 kV lines are currently existing in the southern part of Eastern Denmark (Figure 4-3).

Figure 4-3: Transmission system in Eastern Denmark and areas for existing (green) and future (orange) offshore wind farms [Elkr 04]

4.4 Grid Issues

Transmission Bottlenecks

In Western Denmark as well as in Eastern Denmark, currently a number of bottlenecks exist that would limit the amount of power that could be injected by offshore wind farms. The necessary grid reinforcement are envisaged for the short term (until 2009) as well as for the medium term (until 2012).

In Western Denmark, a number of reinforcements of the 150 kV and 400 kV systems are planned by 2009 requiring no new routes for transmission lines. These would enable the connection of the Horns Rev B project that is scheduled for 2008. In the long run, the 400 kV system would be extended along the west coast of Jutland closing a 400 kV ring between Idomlund and Endrup. Power from offshore wind farms could then be collected offshore and injected at several points at the coast. Moreover, the power as well as the power from onshore wind farms and CHP plants could be transported via the reinforced 400 kV system. Reinforced interconnectors to Germany, Norway and Sweden and an interconnector to the Eastern Denmark could further facilitate this exchange [Eltr 04b].

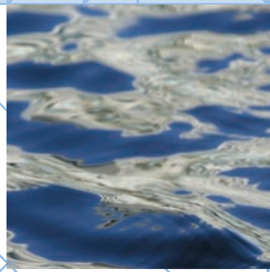
In order to connect the second phase of the Rødsand/Nysted wind farm and possibly a wind farm at Omø Stålgrunde to the transmission system in Western Denmark, reinforcements are necessary in the southern part of Eastern Denmark. This includes the creation of a 132 kV transmission ring by interconnecting Vestlolland and Stignæsværket via a sea cable. This reinforcement has been scheduled to be ready by 2010 [Ener 05].

In the long run the transmission ring in the south of Eastern Denmark could then be upgraded to 400 kV and linked to the 400 kV system in the northern part of Eastern Denmark. In the mean time also the Great Belt interconnector between Eastern and Western Denmark would be established and the connection to Sweden would have been further reinforced [Ener 05].

Grid Connection

Technical regulations for the connection of wind farms to the transmission system (> 100 kV) have recently been published by Energinet.dk [Ener 04]. The regulation contain the following.

- Common power quality requirements



- Power control: very detailed requirements for power control including balance control, delta control, power gradient control and (primary) frequency control (as previously demonstrated at Horns Rev [Chri 03]).
- Reactive power
- Disturbances:
- Frequency: < 47.5 Hz, > 53Hz: switch off immediately
- Frequency: between 51 and 53 Hz: switch off after 3 min
- Frequency : between 47.5 and 49 Hz and between 50.5 and 51 Hz: switch off after 30 min adapt active power in case of disturbances
- Voltage ride through: voltage sag down to 25 % and return to rated voltage within 0.75 s must be ridden through.

The requirements are relatively complex and can be found in detail in [Ener 04]. They also contain requirements for external control and monitoring.

Balancing

The physical balancing of wind power in Denmark lies fully in the responsibility of the TSO who has to buy regulating power on the TSOs regulating market NOIS. Therefore, the TSO applies short-term prediction tools for forecasting. The concept of access or programme responsibility for other market parties is not applied.

4.5 External Factors

Denmark is situated between the hydro power dominated systems in the Nordel zone and the fossil dominated UCTE zone. In the European internal electricity market, it therefore functions as a bridge for extensive power exchanges between these two zones. Therefore, existing transmission bottlenecks in the Danish system are generally subject to competition between commercial exchange power and balancing power flows related to variations in wind farm output. On the other hand, the mitigation of these bottlenecks would be essential for the large-scale integration of wind power in the European context since it contributes to the possibilities of exchanging power between areas with generally different climates.

When interconnector capacity is available, the Nordic hydro power resources could be used to balance fluctuations from wind power in Western Denmark and Northern Germany. However, this is not realised yet practically due to the present settlement model for the power exchange via the high-voltage DC connections between Western Denmark and the Nordel system [Akhm 05].

Moreover, the available interconnector capacity with Germany will be reduced by the increase of installed wind power in Northern Germany as long as no grid reinforcement will be undertaken in Germany [Eltr 04a, Eltr 04b].

4.6 Offshore Cable

Horns Rev A is connected via a 150 kV cable, Rødsand via a 132 kV cable. When Horns Rev will be extended beyond 400 MW collection of power offshore and grid connection at several connection points may be considered. Then these connections will probably be implemented as HVDC connections.

In the long run this could become one of the nodes for a transnational offshore grid in the North Sea [Eltr 04a].

4.7 Conclusions

In Denmark, 4 GW of offshore wind farms are envisaged by 2030, of which most will be connected to the system in the western part of Denmark. In 2004, the total installed wind power generation capacity was more than 3 GW. A number of grid reinforcements will be necessary in order to facilitate the integration of the envisaged offshore wind power.

The Danish grid code requires facilities for stepwise control of active power, power gradient limitations and power output curtailment available to the TSO. Additionally, facilities for primary control should be available for each turbine and voltage ride through capability should implemented on a per-turbine base.

Aside from wind power, distributed, heat driven combined heat and power (CHP) plants are increasingly substituting traditional generation capacity. Therefore, Danish TSOs propose to consider active control of the CHP plants in combination with heat storage and the application of heat pumps.

4.8 References

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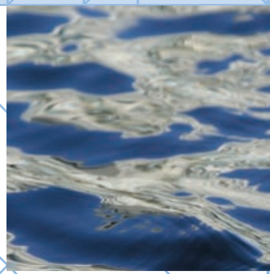

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Germany

5.1 Plans and Prospects

The German government has developed a strategy for the development of offshore wind energy [BMU 02]. The German offshore strategy aims at 20 to 25 GW of offshore wind energy in the German EEZ. By means of spatial planning, the offshore strategy aims on controlling this development quantitatively and over time [BMU 02, Vier 05].

Different scenarios for the offshore development in Germany have been drawn up, for example by DEWI [Moll 04, Dena 05]. In total, applications for more than 60 GW have been filed [Vier 05]. DEWI estimates that realistically 20.4 GW can be realized by 2020 scheduled as in Figure 5-1 [Dena 05]. In 2005, 2.5 GW had been approved with a potential of further extension up to 12 GW and the German government expects a clearly slower development than expected initially [BMU 05, Rehf 02].

When clustering areas for offshore wind energy according to the possibility for grid connection, four areas in the North Sea and two areas in the Baltic Sea can be identified as indicated in Figure 5-2.

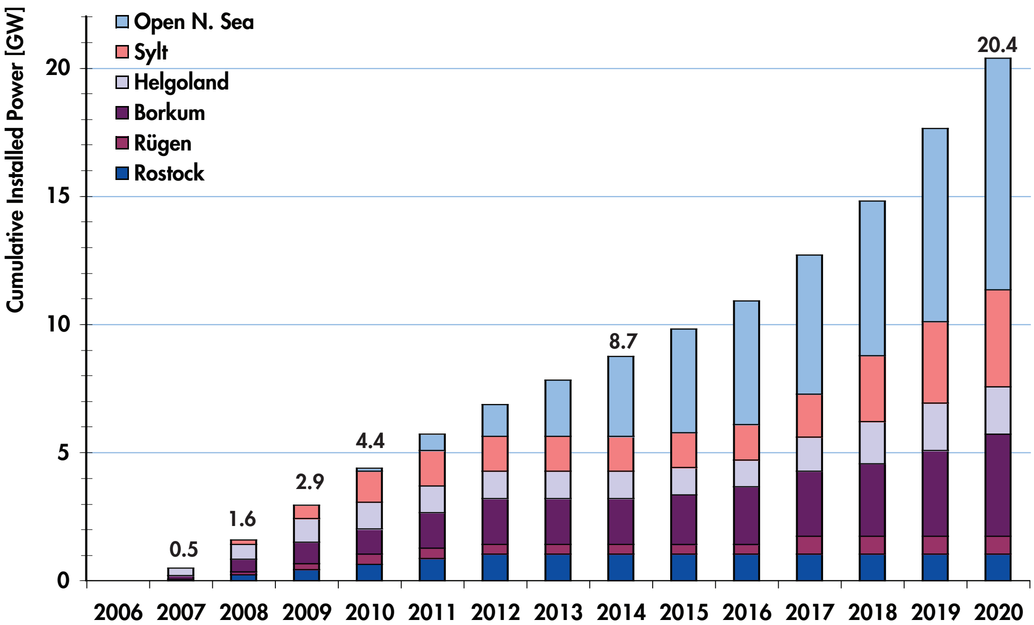
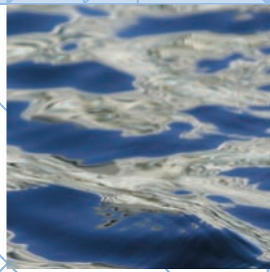


Figure 5-1: Plans and prospects for installed offshore wind power in Germany (North Sea: Open North Sea, Sylt, Helgoland, Borkum; Baltic Sea: Rügen, Rostock) [Dena 05]



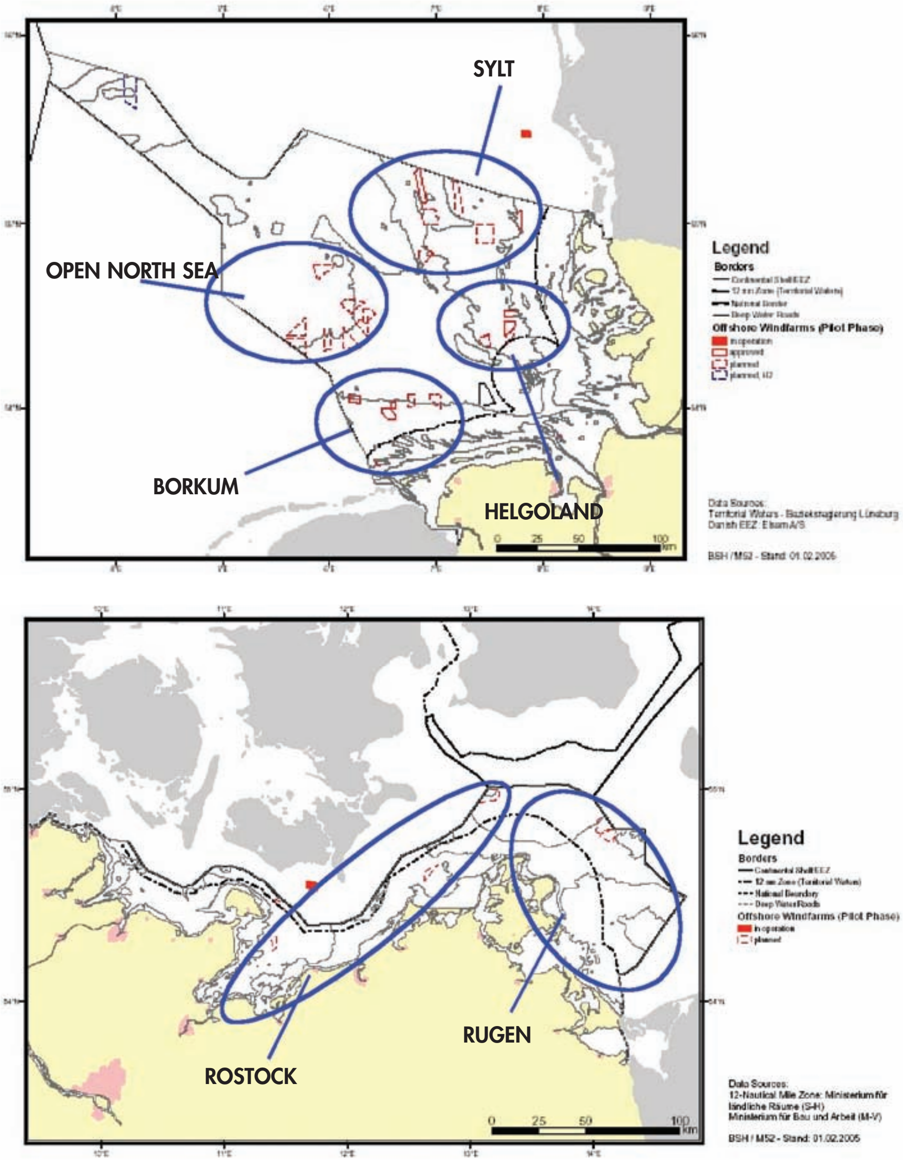


Figure 5-2: German EEZ and planned wind farm sites grouped by area [Dena 05], maps from [Bund 05]

5.2 Power System

Table 3-1 gives the installed power generation capacity on German territory by the end of 2002. The overall generation capacity was 125.0 GW. The maximum load in Germany was approximately 74 GW and the minimum load 38 GW (with 2003 data from [Dena 05]). The final electricity consumption in 2002 was 499 TWh [Euro 04]. The installed wind power generation capacity has grown from 30 MW in 2002 to 95 MW in 2004 [EWEA 05].

The installed wind power generation capacity has grown from 12.0 GW in 2002 to 16.6 GW in 2004 [EWEA 05].

Table 5-1: Installed power generation capacity in 2002 [Euro 04]

Technology	Nuclear	Thermal	Hydro	Wind	Others	Total
Rated power [GW]	23.4	81.1	8.5	12.0	-	125.0
Percentage	18.7	64.9	6.8	9.6	-	100

In Germany the transmission grid covers 220 kV and 380 kV lines. Lines of less than 150 kV are considered distribution lines. The German transmission system is divided into four control areas, each in the responsibility of one TSO: RWE Transportnetz Strom GmbH, E.ON Netz GmbH, Vattenfall Europe Transmission GmbH and EnBW Transportnetze AG (Figure 5-3). The grid of EnBW Transportnetze AG is located in the south west and not directly affected by offshore wind energy generation. Together the four control areas form the German control block, which makes part of the UCTE synchronous zone. Within the UCTE the German control block is represented by RWE Transportnetz Strom GmbH.

Figure 5-3: Control areas of German transmission system operators [VDN 05]

5.3 Offshore Power Injection

Table 5-2 lists the probable connection points for each offshore area. The areas as defined in Figure 5-2 are only indicative. In the Baltic Sea each of the areas has been assigned to one of the two available substations. In the North Sea assignment of each of these areas to substations is not possible. Therefore, the distribution of installed powers over the four North Sea areas in Table 5-2 does not precisely match that from Figure 5-1 although the total installed wind power is identical.

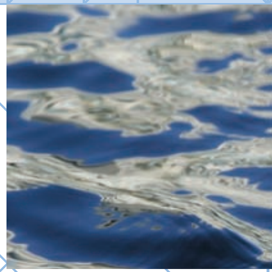


Table 5-2: Eligible substations for the grid connection of offshore wind farms [Dena 05]

Area	Substation	Voltage [kV]	Power [MW]	before date
Open North Sea	Brunsbüttel (Vattenfall)	380	4540	2020
	Conneforde	380	3200	2020
	Moorriem	380	3200	2020
Sylt	Böxlund	380	(125)	(2007)
			640	2010
	Brunsbüttel (Vattenfall)	380	1110	2010
Helgoland	Brunsbüttel (E.ON)	380	750	2010
Borkum	Maade	220	240	2007
	Emden / Borßum	220	60	2007
	Diele	380	(1630)	(2010)
			4900	2020
Rügen	Bentwisch	380	(226)	(2007)
			(611)	(2010)
			1011	2020
Rostock	Lubmin	380	(400)	(2010)
			700	2020

For grid integration of the pursued 476 MW offshore by 2007, a number of grid reinforcements are required. These are due to the high concentration of onshore wind energy installed in the north already, in combination with the additional offshore capacity. For the transmission capacity in 2007, only grid reinforcements realizable by this date have been taken into consideration in [Dena 05], which means new power lines will only be installed on existing systems. With these reinforcements taken into account, curtailment of the wind generation may still become necessary in extreme situations of high wind speed and low load. Unlike estimated in [Dena 05], it is generally not anticipated that these 476 MW will already be installed in 2007 since from 2007 on only the first wind farms will be erected [Vier 05].

The considered reinforcements until 2007 (Figure 5-4) are

- installation of phase shifters, one at substation Brunsbüttel and two at Diele (1400 MVA each),
- reinforcement from 220 kV to 380 kVof several existing lines inland,

- extension of substations and new transformers inland,
- provision of 5600 Mvar of capacitive compensators (capacitors or SVC) at different sites inland.

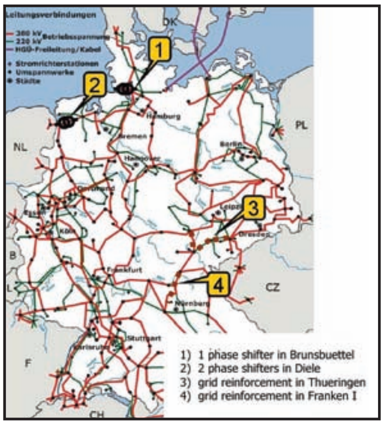


Figure 5-4: German transmission system with reinforcements by 2007 [Dena 05]

5.4 Grid Issues

Transmission Bottlenecks

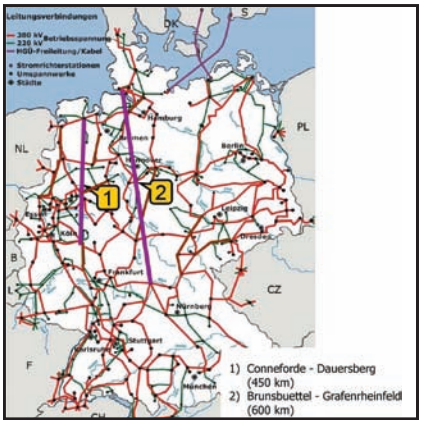
On the long run, power injection from offshore wind parks in the rural Baltic and North Sea regions will be limited by transmission bottlenecks to the load centres: Rhein/Ruhr, Frankfurt, Stuttgart, München.

The total required grid reinforcements and extensions for the horizons 2007/2010/2015 and 2020 have been determined in [Dena 05], without making a differentiating between onshore and offshore wind power. Table 5-3 provides an overview over all measures required.

Table 5-3: Main grid reinforcements and extensions as required in Germany due to onshore and offshore wind energy [Dena 05]

Grid reinforcement	2007	2010	2015	2020
Phase shifters	4200 MVA			1400 MVA
Substations	reinforcements	1		1
	replacements	1	1	1
	new built			2
Grid: new lines	6 km	455 km	390 km	1050 km
Grid reinforcements	269 km	97 km	26 km	450 km

Between 2015 and 2020, an additional 10.3 GW offshore wind power will be installed in the North Sea only. In order to transport this power to the load centres in the centre and south of Germany, the Dena grid study proposes a high voltage DC overlay grid (Figure 5-5) [Dena 05]. This would consist of two high-voltage DC transmission lines from the substations Conneforde and Brunsbüttel at the coast



to, respectively, Dauersberg and Grafenrheinfeld. From Dauersberg the load centres in the west and south west can be supplied and from Grafenrheinfeld those in the south.

Figure 5-5: German transmission system by 2020 with overlay grid [Dena 05]

In [Dena 05] the costs for these reinforcements have been estimated very roughly by the involved TSOs. They estimate that significant costs for grid reinforcements can be allocated to wind energy when the total installed wind power exceeds 20 GW. Beyond 20 GW the specific costs for transmission system reinforcements allocatable to wind energy can very roughly be estimated as €100/kW. With the estimate of approximately 50 GW on and offshore wind energy in 2020 the overall costs for grid reinforcements due to wind energy can be estimated around 3 billion Euros.

Grid Connection

General guidelines for the connection of wind farms to the transmission system have been published by VDN, the association of power system operators in Germany [VDN 04]. Moreover the transmission code is applicable [VDN 03]. The requirements contain the following.

- Common power quality requirements
- Primary control (frequency): not required
- Power control: not required in general; curtailment required in case of specified situations; required power reduction of minimum 10% of installed power per minute
- Reactive power as function of the grid voltage Q(U)
- Disturbances:
    - frequency: < 47.5 Hz (may disconnect)
    - voltage ride through:
      <10%: 0.1 s,
      < 085%: 5 s,
      > 116% 0.1 s;

Dynamic power system studies have shown that in 2015 and beyond the system stability in the event of heavy grid disturbances cannot be guaranteed. This is due to the high amount of older wind turbines with squirrel cage induction machines that did not need to comply with the recent and more sophisticated grid connection requirements [VDN 04], installed onshore mainly in the 1990s. When in

the long run these systems will be repowered the dynamic stability of the power system will be clearly improved [Dena 05].

Balancing

In Germany balancing is taken care of by the TSOs for their control areas [DVG 98]. The concept of access or programme responsibility for other market parties is not applied. All TSOs apply short-term predictions of the accumulated wind power generation in their control areas [Erns 03, Rohr 03, Fock 05].

5.5 External Factors

Power transit from Scandinavia leads to congestion in the north of Germany already today. Wind power imported from Denmark could add up to the power injection from offshore wind in the German EEZ.

With regard to grid reinforcement and power system stability, [Dena 05] does not look at other innovative alternatives like dynamic line ratings, storage or demand control.

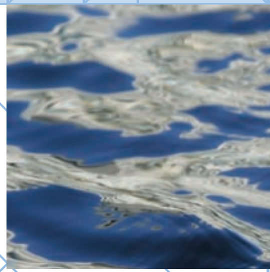
5.6 Offshore Cable

The windfarms in the German EEZ will mainly be connected by means of high voltage AC lines. In the pilot phase these will be 150 kV sea cables.

In the latter phase, beyond 2010, the application of gas insulated lines (GIL) is considered. These lines are suited for a transmission voltage of 400 kV. In that phase, the power from offshore wind farms would be collected at offshore substations via a 220 kV offshore cable grid and there transformed to 400 kV. The power would then be landed via a limited number of GIL lines, thus limiting the number of cables to cross the wadden sea and the coast line. On shore the power transmission would be continued by 400 kV overhead lines towards the selected substations.

5.7 Connection and Energy Pricing

In Germany renewables have priority access to the grid. The connection charges for renewables are shallow [EEG 04]. Power system operators are obliged to buy power from offshore wind farms and make it possible to connect them without compromising security of supply.



Power producers from offshore wind energy receive a fixed price per kWh from the power system operator as specified by the Renewable Energy Act [EEG 04]. The minimum compensation for offshore wind energy is 6.19 cents/kWh. There is an initial higher compensation of 9.1 cents/kWh for energy from offshore wind turbines installed at latest in 2010 for a period of 12 years. This initial higher compensation period is linearly prolonged with increased water depth and distance from the shore [EEG 04].

5.8 Conclusions

The German government has set clear objectives for the utilization of offshore wind energy until 2020 and beyond. In order to achieve these objectives, a number of grid reinforcements will be necessary. The most important have been identified in the framework of the DENA grid report, including a preliminary timing and an estimate of associated costs.

German TSOs see main grid bottlenecks with regard to system stability and advocate the supply of ancillary services from as many as possible wind parks including repowering of older installations. Also they stress the need of transmission reinforcements. In conclusion they consider the grid integration of the pursued wind power possible; however, not without stressing the associated social costs and the remaining uncertainties.

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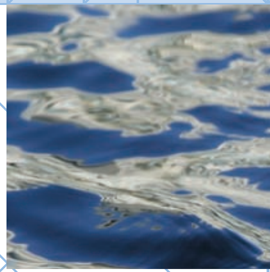


Republic of Ireland

6.1 Plans and Prospects

The mechanism for permitting offshore wind farms in Ireland comprises a "foreshore license." A foreshore license allocates exclusive rights to a single developer to allow in-depth site assessment. In a second step a foreshore lease can be granted that assigns exclusive site development rights to a developer [Lemm 04].

In 2003, 11 foreshore licenses had been issued and one foreshore lease, the latter being for the Arklow Bank. Codling Bank is the next furthest progressed project, having submitted its full application for a foreshore lease. Two other projects, the Kish Bank and the Bray Bank have won power purchase contracts, for 25-MW capacity each, for commissioning by 2006. These projects are all located on the east coast of Ireland [Lemm 04].

At the Arklow Bank 25 MW of offshore wind power has been erected in 2003. Under original plans, a 60-MW phase 2 was scheduled for grid connection in 2005. The potential total capacity for this wind farm is 520 MW. The potential total capacity for Codling Bank is approximately 800 MW. Other projects are also under investigation, but based on these projects alone, the total installed offshore windpower in the Irish EEZ could be about 1370 MW in 2010 (Figure 6-1). However, present grid capacity is constrained and this is discussed in the following section.

Long term prospectives until 2020 have not yet been published. The previous Concerted Action on Offshore Wind Energy in Europe estimated the offshore potential in Ireland at 3300 MW [CA-O 01]. A grid study by Garrad Hassan, mainly based on data from the Irish Department of Energy, estimates the potential for offshore wind power in four of the five foreshore licensed blocks at the Irish east coast at 2.9 GW [Gard 03].

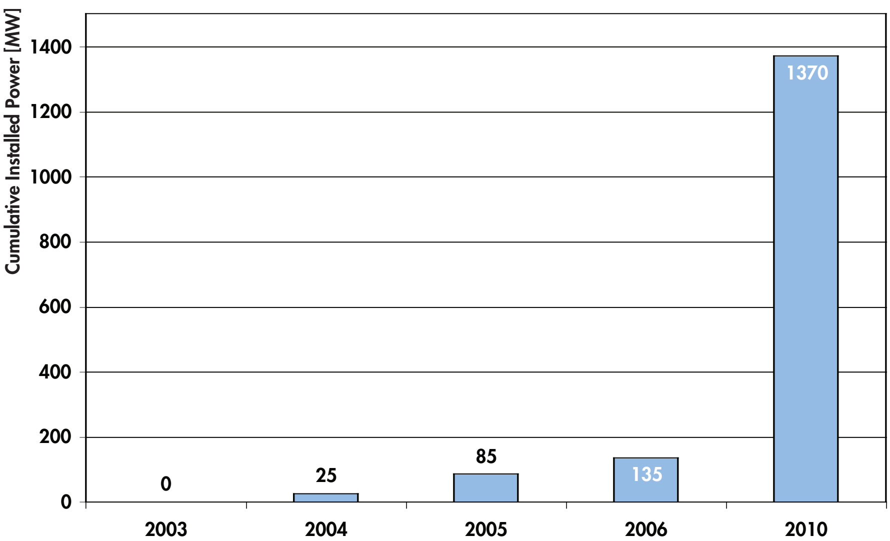


Figure 6-1: Plans and prospects for installed offshore wind power in Ireland [Lemm 04]

6.2 Power System

Table 6-1 gives the installed power generation capacity in the Republic of Ireland by the end of 2002. The overall generation capacity was 5.43 GW. The maximum load in 2002 was 4.24 GW, the minimum load was approximately 1.5 GW. The final electricity consumption in 2002 was 21.8 TWh [Euro 04].

The installed wind power generation capacity has grown from 140 MW in 2002 to 340 MW in 2004 [EWEA 05].

Table 6-1: Installed power generation capacity in 2002 [Euro 04]

Technology	Nuclear	Thermal	Hydro	Wind	Others	Total
Rated power [GW]	-	4.76	0.53	0.14	-	5.43
Percentage	-	87.6	9.8	2.6	-	100

The Irish transmission system consists of 110 kV, 220 kV and 400 kV lines. It is operated by the national TSO ESB National Grid (ESBNG). EirGrid plc will take over responsibility for the transmission system soon as part of the European process of unbundling.

The synchronous zone is the island of Ireland including the transmission systems of the Republic of Ireland and Northern Ireland.

6.3 Offshore Power Injection

At the Irish east coast, three substations are available for power injection from offshore wind energy into the 220 kV system (Figure 6-2) with an incremental transfer capability as in Table 6-2. These substations could serve for connecting the amount of offshore wind shown in Figure 6-1 up to 2006 however, none of them could absorb the nominal power of the Arklow Bank project in its final stage.

Moreover, a number of 110 kV substations are available around the coast of Ireland as indicated in Figure 6-2. The incremental transmission capability of these substations is listed in [ESB 04a].

A detailed examination of the limits for wind power injection at all voltage levels is provided in [Gard 03]; however, without going into further detail for the specific substations for offshore power injection.

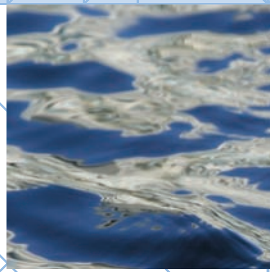


Figure 6-2: National transmission grid with 220 kV substations at the east coast (source EirGrid, from [IEA 04])

Table 6-2: Eligible 220 kV substations at the Irish east coast [ESB 03]

Substation	Voltage [kV]	Incremental Transfer Capacity
Finglas	220	100 – 250 MW
Arklow	220	100 – 250 MW
Great Island	220	0 – 100 MW

6.4 Grid Issues

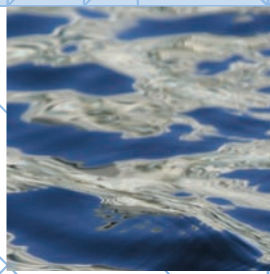
Transmission Bottlenecks

The available substations could serve for connecting the offshore project planned until 2006. Since none of them could absorb the nominal power of the Arklow Bank project in its final stage or any additional projects, additional substations and transmission grid reinforcements will be necessary in the long run. According to ESB NG, the necessary grid reinforcements for the offshore development would be progressed when procured.

Grid Connection

All generators connected to the transmission system have to comply with the Transmission Grid Code [ESB 02]. Moreover, grid-connected wind turbines must respect the Wind Grid Code [ESB 04b]. The Wind Grid Code contains the following:

- Common power quality requirements
- Primary control (frequency):
  • not required in normal operation
  • when frequency exceeds 60-min threshold, apply linear droop
- Power control:
  • power control in case of frequency disturbances (see above),
  • curtailment required in case of specified situations
  • maximum ramp rates between 1 and 30 MW/min over 1 and 10 minutes
- Voltage control:
  • voltage control by reactive power supply
  • reactive power range as specified in the Wind Grid Code
- Disturbances:
  • remain connected with frequency
  between 49.5 Hz and 50.5 Hz: normal operation
  between 47.5 and 52.0 Hz: 60 min
  between 47 and 47.5 Hz: 20 s
  rate of change < 0.5 Hz/s
  • voltage ride through
  >90%: normal operation,
  15%: 0.625 s, 90%: 3 s, with linear slope,



<15%: may disconnect,

- in case of voltaqe dips:
  provide active power proportional to retained voltage,
  maximize reactive power for at least 0.6 s

These requirements are stricter than in most other countries. Taking into account that the Irish synchronous zone contains only a generation capacity of 7 GW the reason for the requirement of wind turbines to participate in frequency control is evident.

Balancing

In Ireland balancing is taken care of by the TSO [ESB 02]. The concept of access or programme responsibility for other market parties including penalties for unbalance is not applied.

The Wind Grid Code obliges operators of Wind Farms of more than 30 MW to provide short-term power forecasts. Moreover, the available wind power output has to be declared whenever changes in available power occur [ESB 04b].

6.5 External Factors

The synchronous zone of Ireland has a relatively small generation capacity leading to relatively small short-circuit levels. Therefore, in Ireland, power system stability is much more an issue than in the UCTE system. Moreover, also the congestion of transmission lines is an issue that needs to be adressed. This is the case for onshore wind energy as well as for offshore wind energy.

Power exchange is only possible with Northern Ireland via the North South Interconnector. The design capacity of this interconnector is 600MVA. An Ireland-Wales interconnector on HVDC is under discussion [DKM 03].

6.6 Offshore Cable

The first 25 MW of the Arklow Bank wind farm are connected at 38 kV to the distribution system at the Arklow substation. For connecting a generator of several hundreds of megawatt this is not feasible anymore and the wind farm will probably be connected to the transmission system. Since the wind farm is relatively close to the shore, DC transmission lines are probably not necessary.

6.7 Connection and Energy Pricing

In Ireland a generator must pay for construction of the physical connection to the transmission system. Moreover, any deep reinforcements required by the TSO are paid for separately by the project developer.

Prices according to the Alternative Energy Requirement (AER) are determined via a bidding system. The most recent one for offshore wind energy this is the Alternative Energy Requirement VI. The price for offshore wind energy is capped at 8.4 cents/kWh [Vrie 03]. However Arklow operates without an AER contract.

6.8 Conclusions

The maximum possible offshore wind power that could be injected in the Irish transmission system is limited by the incremental transmission capability of the substations at the coast. The construction and reinforcement of transmission lines or substations in order to accommodate larger amounts of wind energy is not considered to be difficult by the TSO, but there are matters of cost and consents, out with the TSO's remit, which need to be addressed.

Dynamic system stability with a high share of wind power and balancing of the transmission system are generally considered as more technically challenging . Accordingly, short-term predictions of wind farm output are already today required by the Wind Grid Code of ESB National Grid. This is a consequence of the small size of the power system of the island of Ireland as an independent synchronous zone.

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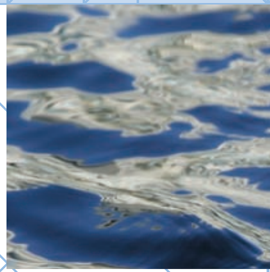

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Netherlands

7.1 Plans and Prospects

In the Netherlands, 6000 MW offshore wind power and more could be installed by 2020. The technical potential is still much higher. Different scenarios for installed capacity, available areas, consequences for the transmission system, and several options for the offshore connection have been studied (Figure 7-1). The best suited areas for offshore wind energy identified by this study are those not excluded due to other activities and close enough to shore to keep the grid connection and foundation costs relatively low [Hond 04].

The most probable zones for offshore wind energy in Dutch waters with a technical potential of 10 GW are indicated in Figure 7-2. The colour code indicates the energy production cost as a function of the site.

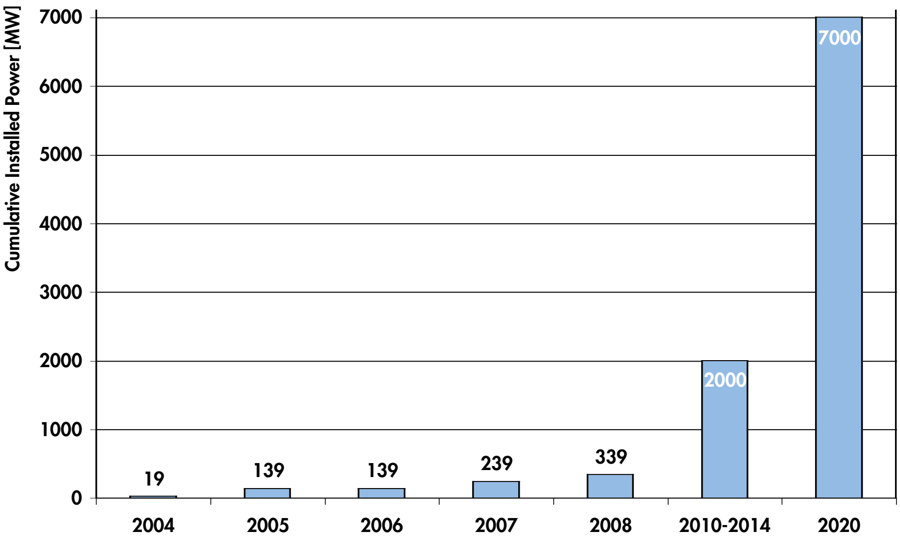


Figure 7-1: Plans and prospects (baseline scenario) [Hond 04]

7.2 Power System

Table 7-1 gives the installed power generation capacity in Netherlands by the end of 2002. The overall generation capacity was 20.8 GW. The maximum load in 2002 was 15.0 GW, the minimum load was 5 to 6 GW. The final electricity consumption in 2002 was 99.7 TWh [Euro 04].

The installed wind power generation capacity has grown from 680 MW in 2002 to 1080 MW in 2004 [EWEA 05].

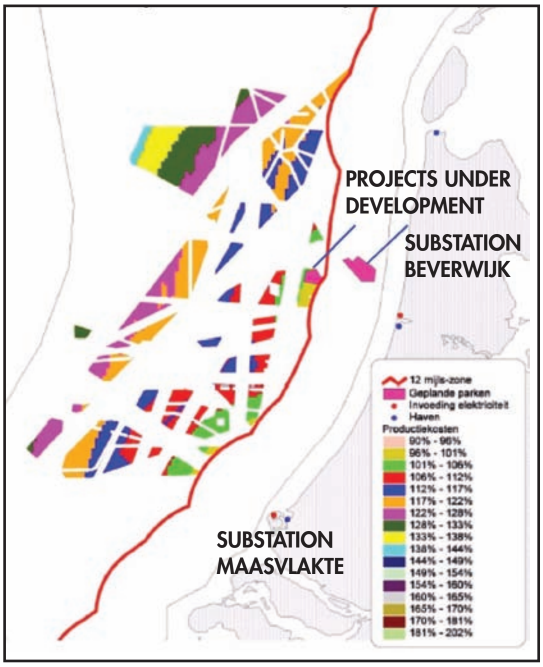


Figure 7-2: Economically best suited sites for offshore wind parks in the Dutch EEZ [Hond 04]

Table 7-1: Installed power generation capacity in 2002 [Euro 04]

Technology	Nuclear	Thermal	Hydro	Wind	Others	Total
Rated power [GW]	0.45	19.63	0.04	0.68	-	20.80
Percentage	2.2	94.3	0.2	3.3	-	100

The Dutch 380 / 220 kV transmission system is operated by Tennet. Lines of 150 kV and less are operated by regional power system operators, independently of whether these regards transmission or distribution lines. The Dutch transmission system makes part of the UCTE synchronous zone.

7.3 Offshore Power Injection

In the Netherlands, four 380 kV connection points close to the coast were initially considered in the under consideration in [Cleij 03]: the substations Borssele, Maasvlakte, Beverwijk and Eemshaven. From the previously identified areas the substations Maasvlakte and Beverwijk are the best eligible for offshore wind power injection.

Currently, wind power injection in Beverwijk and Maasvlakte is limited to 500 and 1500 MW, repectively (Table 7-2). The grid map in Figure 7-3 contains already the grid extensions as they have been scheduled in the TSO’s capacity plan until 2007. Currently, Beverwijk does not yet have a 380 kV connection and the first two projects NSW and Q7 will be connected to the 150 kV power system of the regional operator Continuon.

When the 380 kV system has been extended to Beverwijk, the maximum injectible power in Beverwijk will become 1500 MW. Power transmission will then be limited further inland by the lines from Diemen to Lelystad and from Lelystad to Ens (Table 7-3).

Figure 7-3: National transmission grid after 2007 [KEMA 02]

Table 7-2: Eligible substations for the grid connection of offshore wind farms [Hond 044]

Substation	Voltage [kV]	Incremental Transfer Capacity
Beverwijk	380	500 MW to Diemen
Maasvlakte	380	1500 MW to Krimpen

Table 7-3: Zones for offshore wind parks and available export capacity at the eligible substations

Zone	Prospects	Substations	Total export capacity
Aim by 2020	> 6000 MW	Beverwijk, Maasvlakte	2000 MW

7.4 Grid Issues

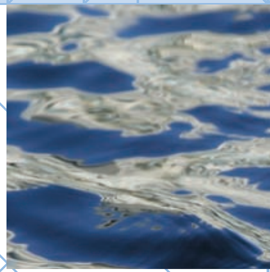
Transmission Bottlenecks

The Connect 6,000 MW study gives rather precise time schedules for the necessary grid reinforcements. Reinforcement of a line is expected to take 9 up to 14.5 years. In the optimistic case, the required 6000 MW could be accommodated by the transmission system in 2012 whereas in the pessimistic case the maximum injection capacity will remain limited to 2000 MW until 2018 [Hond 04].

The costs for these grid reinforcements are estimated to be in the range of 281 million Euro if all cables run above ground. If up to 30% of the new lines have to be underground, the cost may be up to 839 million Euro.

The identified transmission bottlenecks become most significant when power is exported to Germany and Belgium.

Possible, HVDC transmission lines will be constructed to Norway (NorNed cable 700 MW) and to Britain (BritNed cable 1320 MW).



Grid Connection

General guidelines for the connection of wind farms to the transmission system have not yet been published in the Netherlands. In order to be able to inject 6000 MW from offshore wind farms, capacitor banks will be required at the points of injection [KEMA 02]. The impact of offshore wind energy on the dynamic stability is also addressed here and respective studies are suggested. The impact of short variations in wind speed on the primary control is expected to be much less severe than the power loss due to a fault of a large generation unit. Sudden shut down of large wind farms due to extremely high wind speed is addressed in the same study as a major point of concern. Finally, although stressing its importance, the study does not make precise statements about the impact of the electrical wind turbine drive concept on these aspects [Cleij 03].

Balancing

In the Dutch liberalized electricity market, balancing lies in the responsibility of so-called Program Responsibles (Programmaverantwoordelijke, PV). The PV is responsible towards the TSO to maintain the quarterly power balance over all its connection points. Deviations from the schedule are penalized by the TSO.

A PV with a high share of wind power in its portfolio will have higher imbalance than others. As a consequence, the PV will allocate penalties due to imbalance to the wind farm operator. On that background short-term wind power forecasting will become crucial.

7.5 Offshore Cable

Different options are discussed for the offshore connection:

- classical HVDC connection and HVDC light connection with voltage source converters,
- one 380 kV cable per wind park,
- a 380 kV offshore grid.

A hybrid between the last two possibilities seems to be the most likely. In Maasvlakte, it is not feasible to cross the coast line with individual cables for each offshore wind park individually. Although in Beverwijk, individual connections may be possible also there a concerted approach is recommended.

The most promising option seems to extend the 380 kV system through the coast line to the border of the 12 mile zone where an offshore substation should be installed. Different offshore projects could then individually connect to this substation [Hond 04, Derk 04].

7.6 Connection and Energy Pricing

Connection charges are deep and negotiated between parties for DG above 10 MVA [Donk 04].

7.7 Conclusions

The main bottleneck for the large-scale deployment of offshore wind energy in the Netherlands is the transmission capacity of the high voltage grid. Currently, 2000 MW of offshore wind power could be accommodated.

The necessary grid extensions in order to accommodate more power have been inventoried and their costs have been estimated. The actual progress of grid reinforcements will depend on concrete application of projects but also on the necessary permission procedures for new high voltage lines.

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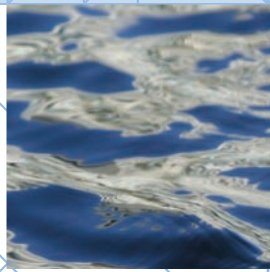


Poland

8.1 Plans and Prospects

In Poland, no specific areas have been designated to off-shore wind energy generation. Most projects are concentrated on the central part of the coast and two farms with more than 100 MW are planned east of the Gulf of Gdansk (Figure 8-1). Realistically, 150 MW of offshore wind farms could be commissioned by 2010. The total of filed applications and other projects under consideration, offshore and onshore, are about 1500 MW [Onis 01].

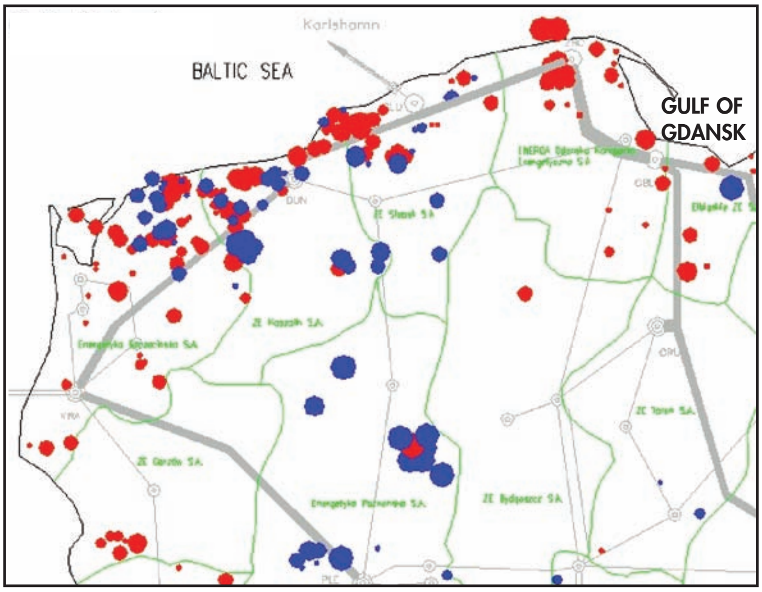


Figure 8-1: Spatial distribution of future wind energy projects at the Polish coast (red: planned, blue: considered).

8.2 Power System

Table 7-1 gives the installed power generation capacity in Poland by the end of 2002. The overall generation capacity was 34.95 GW. The maximum load in 2002 was 23.86 GW, the minimum load was 14.66 GW. The final electricity consumption in 2002 was 137.06 TWh [PSE 05].

In 2004, the cumulative installed wind power generation capacity was 63 MW [EWEA 05].

Table 8-1: Installed power generation capacity in 2002 [PSE 05]

Technology	Nuclear	Thermal	Hydro	Wind	Others	Total
Rated power [GW]	-	32.69	2.18	0.06	0.02	34.95
Percentage	-	93.5	6.2	0.2	<0.1	100

The Polish transmission system is operated by PSE-Operator SA. It contains lines of 750 kV, 400 kV and 220kV. PSE-Operator also operates the 110 kV distribution system. The Polish transmission system makes part of the UCTE synchronous zone.

8.3 Offshore Power Injection

At the Polish coast a number of substations are available for the connection of offshore wind farms (Table 8-2). Generally the grid is relatively strong at the coast. Local bottlenecks may appear in the future.

Table 8-2: Eligible substations for the grid connection of offshore wind farms [PSE 05]

Voltage [kV]	Substations
220	DUN, PLC, REC
400	ZRC, SLK, DUN

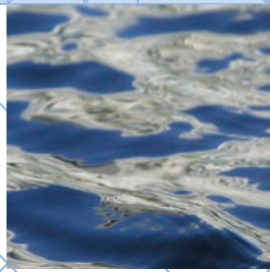
8.4 Grid Issues

The Polish TSO PSE-Operator has prepared a study about the grid connection of wind farms [Czar 03, Jani03a, Jani 03b]. This study does not specifically deal with offshore wind energy and consequently no offshore-specific bottlenecks are addressed. Obviously, the grid integration of wind farms on shore is currently in Poland a much more important issue than the connection of the still relatively small amount offshore.

Balancing in Poland is the responsibility of the TSO. Operators of large wind farms have to submit short-term predictions of their generation and are penalized for deviations. A number of aspects with regard to pricing, grid access and balancing are not yet clarified in Poland. They will be integrated into an amendment of the Energy Law that will come into force soon.

8.5 Connection and Energy Pricing

In Poland the connection charges are negotiated for distributed generation as well as for large offshore wind farms. The planned Energy Law envisages a reduction of the connection charges to half of the power system operator's connections costs for renewable energy installations. The other half will be recovered via the distribution and transmission tariffs.



Renewable energy producers in Poland have priority access to the grid. However, there is no minimum price for renewables. The coming Energy Law envisages minimum prices for electricity from renewable sources as a market average price of electricity from the previous year. This minimum price will be announced every year by the regulator.

8.6 Conclusions

Offshore wind energy deployment in Poland is still in an early stage. The grid study regarding the grid integration of wind energy mainly concentrates on onshore wind. Generally the grid is relatively strong at the coast. Local bottlenecks may appear in the future.

8.7 References Poland

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Sweden

9.1 Plans and Prospects

Offshore wind farms are planned in the southern and central part of the Swedish coast as shown in Figure 9-1. The Swedish government wants to generate 10 TWh from wind energy by 2015 [Swed 01], which will require approximately 4 GW installed generation capacity [Mate 04].

For the end of 2008, BTM Consult forecasts 1348 MW of total installed wind power of which 561 MW offshore [BTM 04]. Longer-term objectives for the development of offshore wind power in Sweden are not available. The previous Concerted Action on Offshore Wind Energy in Europe estimated the offshore potential in Sweden at 7000 MW [CA-O 01].

Figure 9-1: Plans and prospects for offshore wind energy in Sweden [CVI 03]

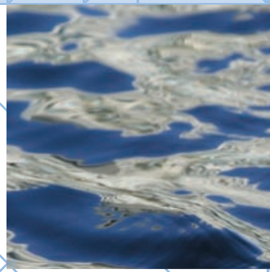
9.2 Power System

Table 3-1 gives the installed power generation capacity on Swedish territory by the end of 2002. The overall generation capacity was 33.22 GW. The maximum load in 2002 was approximately 26 GW, the minimum load was 9.2 GW. The final electricity consumption in 2002 was 131.6 TWh [Euro 04].

The installed wind power generation capacity has grown from 350 MW in 2002 to 440 MW in 2004 [EWEA 05].

Table 9-1: Installed power generation capacity in 2002 [Euro 04]

Technology	Nuclear	Thermal	Hydro	Wind	Others	Total
Rated power [GW]	9.45	6.85	16.57	0.35	-	33.22
Percentage	28.4	20.6	49.9	1.1	-	100



The Swedish nation-wide transmission system is owned and operated by Svenska Kraftnät. The transmission voltage is 220 kV or 400 kV. Regional sections of the power system with voltages of 40 to 130 kV are connected to the national grid and owned by regional system operators. The Swedish transmission system is one single control area operated by Svenska Kraftnät. It makes part of the Nordel synchronous zone together with Finland, Norway and the eastern part of Denmark.

9.3 Offshore Power Injection

Figure 9-2: Nordel transmission system [Sven 05]

The Swedish coast is long and there are several places along the coast where power from off-shore wind farms could be landed. Therefore, the availability of substations will likely not become a major hindrance for the grid integration of offshore wind power. The voltage of these substations today ranges from 70 kV up to 220 kV.

Power injection from offshore wind farms will at maximum be a local problem if more than 500 MW is built in a small region. For Sweden as whole more than 5000 MW could be input if not in the same region.

9.4 Grid Issues

Transmission Bottlenecks

The Swedish power system uses a high fraction of hydropower. The large hydropower plants are situated in the north of the country while the load centres are in the south. Eight 400 kV transmission lines are available to connect the northern part of the transmission system to the central and southern

parts, where the main load is concentrated [Arnb 02]. During periods of high load and availability of hydropower, these lines are operated close to their limit of 7 GW [Mate 04] and form a bottleneck for the generation of further wind power in the north. Bottlenecks also exist for export to neighbouring countries. Generally spoken, new generators can easier be connected in the south of Sweden.

Since offshore wind farms will rather be built in the southern part of the Swedish EEZ, offshore wind power will not be affected by this bottleneck. Conversely, offshore wind power may contribute to mitigate this problem when the load centres in the south in winter and spring can be supplied from offshore wind farms instead of the hydro plants in the north.

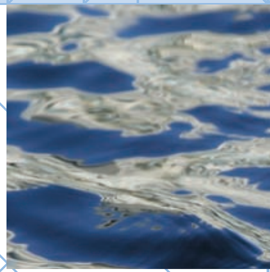
There are no plans for reinforcements due to offshore wind power. However, reinforcements are required for the function of the deregulated power market. Planned reinforcements are Nea-Järpströmmen (to Norway), Hallsberg-Skåne and Fennoskan (to Finland). These reinforcements are supposed to be finished by 2009 to 2012.

Grid Connection

At the moment, in Sweden, there are no regulations for the connection. Regulations for the connection of generators to the grid (at distribution, regional transmission, and national transmission level) are under preparation. The regulations will possibly be issued during 2006.

Preliminary requirements have been published in [Sven 02] and summarized in [Mate 04] as follows:

- Common power quality requirements
- Power control:
  - curtailment to £20% of maximum power in 5 s, when demanded
  - no simultaneous shut down of all wind turbines at high wind speed
- Voltage control:
  - Wind farm equipped with automatic voltage control (±10%)
  - Power factor should be unity
- Disturbances:
  - remain connected with frequency
    between 49 Hz and 51 Hz: normal operation
    below 47.5 and above 55.0 Hz: 30 min, afterwards disconnection
  - voltage ride through
    >90%: normal operation,
    <90%: disconnection after >0.75s
    <25%: disconnection after >0.25s (applies to wind farms < 100 MW),
    =0%: disconnection after >0.25s (applies to wind farms > 100 MW),



A thorough comparison of the Swedish situation with other countries is available in [Mate 04] and [Boli 03].

Balancing

Svenska Kraftnät is responsible for the technical management of the transmission system including the "balance service". The economic responsibility for the balance is; however, put on the so-called "balance providers", typically the big suppliers and producers. The balance providers are responsible for keeping balance of their production and consumption to the system for their respective responsible share on an hourly basis. To do this they can buy and sell electricity on the Nord Pool spot market. The spot market closes at noon the day before delivery. The balance providers can also adjust their trade of production and consumption by hourly contracts which can be set as late as one hour prior to delivery on the "adjustment market".

Physically balance is kept by the primary and secondary control of generators with active power controller. The primary control is automatic. SvK has contracts with certain production units that participate in the primary control. When part of the primary control power has been used, the balance is restored by the secondary control. This is done by the balance service buying or selling power on the "regulation market" [SvK 04].

9.5 External Factors

Possibly, the scheduled reinforcements of the connectors to Norway and Finland will also enable the export of wind power from the North of Sweden. However; this is not specific to wind power and it will only marginally affect the offshore power production.

9.6 Offshore Cable

The first Swedish offshore wind farms have been connected to the distribution system as follows:

- Bockstigen (2.5 MW) via a 10 kV cable to the 10 kV network
- Utgrunden I (10.5 MW) via a 10 kV cable to the regional 50 kV network
- Yttre Stengrund (10 MW) via a 10 kV cable to the regional 50 kV network

New projects in planning will land at higher levels. The Utgrunden II wind farm with planned 90 MW will have a 30 kV AC cable connection to the shore. There it will be connected to the regional 130 kV system.

9.7 Connection and Energy Pricing

In Sweden, connection charges for DG and also for large wind farms are generally deep. Since no priority access is defined in the Swedish legislation, for the connection of offshore wind farms, project developers would have to fund a dedicated company for operation of the offshore lines. Installation costs and also costs for operation and maintenance of these lines would not be socialized but had to be carried by the line operator. The costs would finally be billed to the project developer as transmission cost [Swed 97].

Renewable energy is supported via green certificates. Since certificates have no determined minimum price, no minimum price for wind energy is determined either.

9.8 Conclusions

In Sweden no significant transmission bottlenecks to offshore wind power exist. Installed around the southern part of the Swedish coast, offshore wind farms could rather contribute to the reduction of congestion on the north south connection lines. This situation is due to the situation of large hydropower capacities in the North while the load centres are in the south of the country. Substations for grid connection should be available.

Barriers to the grid integration of offshore wind energy in Sweden are rather imposed by legal barriers. Especially the deep connection charges and the associated high risk for a dedicated system operator for offshore cables add to the uncertainties for offshore wind farm development in Sweden.

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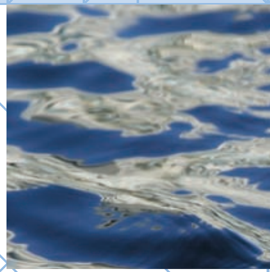

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United Kingdom

10.1 Plans and Prospects

The results of the 'Round One' process of UK Offshore WInd Development were announced in 2001, consisting of 18 sites of up to 30 turbines around the UK coast. Almost all of these now have the necessary consents (total 1 GW), two are in operation (North Hoyle and Scroby Sands), a third (Kentish Flats) is under construction and two more (Barrow and Gunfleet Sands) are near to construction [BWEA 05].

In 'Round Two', three areas were designated for offshore wind energy: North West, Greater Wash and the Thames Estuary (Figure 10-2). Leases for projects totalling 7.2GW were announced in December 2003. Figure 10-1 gives one possible timetable for exploitation (based on BTM's 2004 forecast for UK offshore wind), although progress in 2004 and 2005 is less than shown here. The technical potential for offshore wind energy and other marine renewables in UK waters is much higher than the 8.2 GW currently in process.

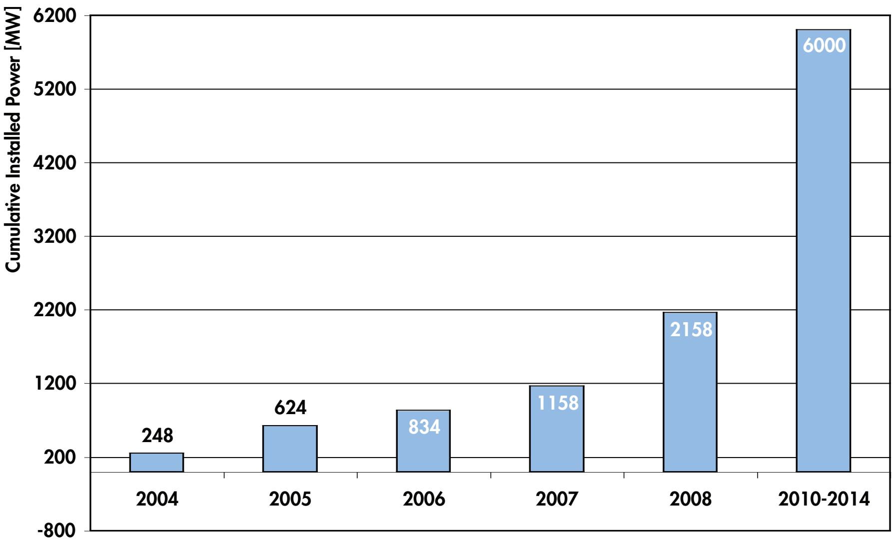


Figure 10-1: Plans and prospects [BTM 04]

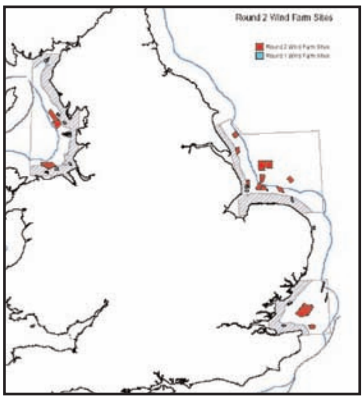
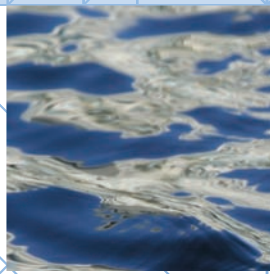


Figure 10-2: United Kingdom and granted domain concessions for offshore wind energy [Crow 04]



10.2 Power System

The power system in Northern Ireland (NI) is part of the synchronous system of the island of Ireland, together with the power system of the Republic of Ireland (ROI). The transmission system owner and operator (TSO) in NI is SONI.

The power system of England, Wales and Scotland (Great Britain or GB) is a separate synchronous system. From April 2005, the system is operated by National Grid Transco (NGT). NGT also own the system in England and Wales, but the transmission systems of northern Scotland and southern Scotland are owned by separate organisations. The GB system has been operated as one unit for decades.

The GB system is asynchronously connected to the island of Ireland by a DC link (effectively 450 MW) and to France and the UCTE system by a DC link (2000 MW). An interconnector to the Netherlands is planned.

The transmission system consists of 400 and 275 kV lines, and 132 kV in Scotland.

Table 10-1 gives the installed power generation capacity in the UK (GB and NI) by the end of 2002. The overall generation capacity was 77.06 GW. The maximum load in 2002 was 61.7 GW, the minimum load was about 20 GW. The final electricity consumption in 2002 was 332.7 TWh [DTI 05a, Euro 04].

The installed wind power generation capacity has grown from 530 MW in 2002 to 890 MW in 2004 [EWEA 05].

Table 10-1: Installed power generation capacity in 2002 [Euro 04]

Technology	Nuclear	Thermal	Hydro	Wind	Others	Total
Rated power [GW]	12.49	59.66	4.38	0.53	-	77.06
Percentage	16.2	77.4	5.7	0.7	-	100

10.3 Available substations

Connection options are confidential to each project developer and are not publicly available. Some information can be gained from the TSO published forecast for the system [NGT 04a], and a recent review of connection options [DTI 05b].

For the North West area, the 132 kV system is weak, but there are 400 kV substations at Deeside, Capenhurst, Frodsham, Stannah and Heysham.

For the Greater Wash area, there are many connection points available on the 132 kV system close to the coast, but these will not be suitable for the largest wind farms. There are 400 kV substations at Grimsby, Killingholme, Spalding, Walpole and Norwich.

For the Thames Estuary, there are many possible connection points at 132 and 400 kV close to the coast, both west and south of the proposed wind farms.

It should be noted that the size of the proposed UK developments may well justify the construction of new substations on the transmission system. Also, the existence of a suitable substation may not be sufficient: it may be necessary to reinforce the transmission system elsewhere in the area.

10.4 Grid issues

Transmission Bottlenecks

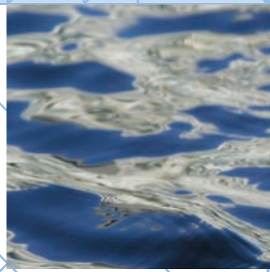
The major transmission bottlenecks for wind generation in the UK are likely to be due to onshore wind in northern and southern Scotland. The net power flows in the UK are already strongly north to south, and expected wind developments in Scotland will require major transmission system reinforcement, which is anticipated to be ready no earlier than 2008.

The situation for offshore wind in the three identified Round 2 areas is less extreme. A total of 1455 MW of offshore wind is already identified in the TSO plans (455 MW in North West to connect in 2006/07, and 1000 MW in the Thames Estuary to connect at 200 MW/yr from 2006/07 onwards). This means that any transmission reinforcement that will be required has already been identified, and could be in place in time for the planned connection dates.

Figure 6.1 of the Interim GB Seven Year Statement (SYS) [NGT 04a] makes it clear that more generation in the North West (including offshore wind farms above the 455 MW already assumed) will require transmission reinforcement to export power south. It should be noted that NGC's interim SYS was produced under time pressures for the first time as a GB-wide document, and hence connection dates contained therein are not binding until further assessment has been undertaken.

The situation in the Greater Wash is not so critical: up to 1.5 GW of new generation, including offshore wind farms, may be possible in that area without transmission reinforcement being necessary. It should be noted that some offshore wind projects in the Greater Wash may wish to connect further north, and would then require transmission reinforcement.

The offshore wind farms in the Thames Estuary (above the 1000 MW already assumed in the SYS) should not require transmission reinforcement, unless other generation projects are built in the area, which use up the available capacity.



The principle in GB is that transmission reinforcements will be built to meet the needs of generators and demand customers. The costs of doing this are reflected back to project developers through geographically-based charges, and in principle this should result in optimal decisions about generator location. Therefore, 'bottlenecks' cannot occur due to institutional issues or Government reluctance to invest in the transmission system. Bottlenecks can only occur due to:

- Medium-term (years) delay in permitting and building transmission reinforcements. It is already recognized that wind farms can be built faster than transmission capacity.
- Public objection to new or reinforced transmission lines, where alternative options are so limited that this results in a long-term restriction. This may apply for onshore wind developments in Scotland, but should not affect the Round 2 offshore projects.

Several studies have considered the transmission system reinforcement that may be necessary for a range of scenarios (in particular [Strb 02, DTI 03, Netw 01]). The results show that the costs, while substantial, are not sufficiently high to rule out wind generation as an attractive option.

Grid Connection

The grid connection process for wind generation, including offshore wind, is becoming more formalized. In principle, the process is indifferent to generating technology. The technical requirements for generators are covered in the Grid Code (and for lower voltage levels, the Distribution Code). There is now one Grid Code for GB, and it is now written to include wind generators and other non-conventional generating technologies.

Several technical issues have had to be resolved, as in many other European countries, and the requirements that have emerged are similar to those elsewhere. As the GB system is much smaller than the UCTE system, the effects of high wind penetrations are more important, and much attention has been paid to issues such as fault ride-through. The TSO has been particularly concerned about the effect of a fault on the transmission system, which would cause severe voltage depressions across large parts of the UK, and could cause large amounts of wind generation to shut down. This problem is now much better understood, but cannot be considered to be entirely resolved, as there is still doubt about the accuracy of the simulation models of wind generation which are available, and their validation. However, this and other issues are at least defined, and all parties appear to be engaging in a process to resolve them.

Balancing

Generators sell their output to electricity suppliers, who then sell it on to customers. Both electricity suppliers and generators need to provide forecasts of their planned demand and generation

respectively by 'gate closure time' (1.5 hours ahead of real time). Up to and in real time, the TSO buys balancing services from generators and load customers in order to balance demand and supply.

Generators and suppliers are penalized for their errors (forecast vs. outcome). If embedded, wind energy can be treated as negative demand. Therefore, to-date it has been best for wind generators to sell their output to an electricity supplier who has a large enough demand under the same grid supply point to absorb fluctuations in wind farm output. In principle, wind generated electricity will trade at a slight discount in order to recompense the supplier for the contribution to its net costs of forecast errors.

Several studies have attempted to quantify the additional balancing costs that will arise with higher wind penetrations. There is wide disagreement in how much reserve or 'backup' plant is needed due to wind (e.g. [Strb 02, NGT 04b]), but the conclusions of detailed studies indicate that the cost, though significant, is insufficient to make wind an unattractive option.

Ancillary Services

The Grid Code (Connection Conditions) defines three types of Ancillary Services:

System ancillary services (mandatory)

These are reactive power control, and frequency control. The requirements are defined elsewhere in the Grid Code. Most wind turbine manufacturers can now meet the reactive power control requirements, and can meet or are working towards meeting the frequency control requirements. Note that the frequency control requirements may result in significant loss of output from wind generation, and so it is intended that this function will only be exercized when all other sources of frequency control have been used.

System ancillary services (by agreement)

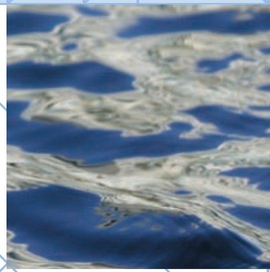
Wind generation is not suitable for these services.

Commercial ancillary services

The specific services are not defined in the Grid Code. There are some services which the TSO may wish to source from wind farms, but in general the options for doing so are liimited, and no such arrangement is known.

10.5 External Factors

New generation projects may be announced, which would alter the assumptions in the SYS and result in significant delays and costs for offshore wind projects which have not yet signed a connection agreement. The opposite to this is where projects fall out of the queue or existing stations close.



10.6 Offshore Cable

The existing UK offshore projects connect to shore at 33 kV. Most future projects will use higher voltages, either 132 kV or possibly 245 kV [DTI 05b].

10.7 Connection and Energy Pricing

The principles of charging for connection are changing, particularly in Scotland where from April 2005, NGT takes over the TSO role. The general principle is a shallow or very shallow connection charge, with annual Transmission Use of System charges with a strong locational element. These favour generation in the south.

In principle, the regulatory framework will allow offshore cable systems to be operated as a separate transmission system, and this may happen, particularly where there are advantages to several wind farms in sharing common connections to shore.

At present, there is a bottleneck in providing significant reinforcements, because even though connection to the transmission is shallow, generators are asked to provide credit cover for the required investment. This issue is subject to ongoing negotiation.

A particular feature of the UK system, which is different from some other jurisdictions, is that there is no guaranteed purchaser of the power generated. Wind projects must find a purchaser, preferably under a long-term contract. There is no minimum or guaranteed price. The Renewable Obligation Certificate system supports all renewable technologies, by providing a guaranteed market. A percentage of each electricity supplier's sales must come from specified renewable sources, and this percentage will be increased annually in order to meet Government targets. This results in a market which should result in the lowest-cost technology being favoured. Currently there is insufficient renewable electricity production to meet the obligation, and so prices for renewable electricity are high.

Capital grants specifically to encourage offshore wind have been awarded to Round 1 projects.

10.8 Conclusions

The effect of the transmission system on the development of offshore wind generation in UK waters does not present a fundamental restriction. It will result in costs, and may possibly result in a slower rate of development.

There are technical, regulatory and commercial issues to be resolved, but none are insoluble, and Government, the wind industry and the TSO are giving a relatively high priority to such issues.

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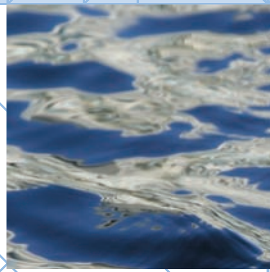

Analysis of country-specific information

From the analysis of information from the eight countries a number of issues can be identified that are common to several of these countries. Depending on the geographical situation or historically evolved grid topologies, countries can be clustered according to the synchronous zone to which their power system belongs. These clusters of countries correspond to a large extent to the regions between which there is limited mutual exchange capacity, as indicated by the priority axes of the European TEN-E action.

11.1 Central and Western Europe

Belgium, the Netherlands, Germany, Poland and the western part of Denmark make part of the UCTE grid. This grid is highly meshed and contains a large traditional generation capacity providing high short-circuit power. The grid is very stiff. Therefore, the impact of offshore wind power on the grid frequency is generally not considered a problem. In addition, the problem of voltage control is considered minor if in the future wind turbines with reactive power control and voltage ride through capabilities are applied.

With exception of the coast of Holland, the coastal areas in Central and Western Europe are rural. Industrial areas are typically situated inside the country. Therefore, in these countries, energy from offshore wind farms will have to be transported to the load centres. On its way through the transmission system this power often has to compete for transmission capacity with power imported from abroad or on transit.

Power injection from offshore wind farms in these countries is limited by the availability of large substations in the coastal regions and by the transmission capacity to the load centres. The necessary grid reinforcements in Germany, the Netherlands and Belgium have already been identified. Adequate grid reinforcements are under consideration, including innovative approaches such as long high-voltage DC cables to form an overlay grid onshore. The main uncertainty for offshore wind energy is the timing of these reinforcements. In particular, the permitting procedure for 400-kV overhead lines can be very protracted, and uncertain. In this situation, TSOs will initiate the required major grid reinforcements only when substantial applications for grid reinforcement have been filed. On the other hand, project developers will make considerable investments only when the grid connection of a wind farm at the time of commissioning can be guaranteed.

11.2 The British Isles

The power systems of the islands of Ireland and Great Britain each form a separate synchronous zone connected to each other, and to continental Europe, only by weak high-voltage DC links. Therefore, an

issue for the grid integration of large wind farms (on- and offshore) is power system stability. As such, in Ireland and the UK, large wind farms are now required to participate in primary (frequency) control, at least in situations where the power system stability is threatened. Moreover, reactive power control and voltage ride through capabilities are specified in grid codes.

In Ireland and the UK grid bottlenecks are also considered an obstacle to offshore wind energy. There is now a transparent process by which new transmission capacity can be built in response to the development of new generation projects, without (as a rule) requiring political intervention. The costs for these reinforcements are not considered an obstacle for wind generation if viewed in the context of total power system costs, although where costs allocated to a particular region or group of projects, grid reinforcements can become a barrier. It is likely that the grid connection of some offshore wind farms could be delayed (or prevented, if planning permission is not granted) because of the time required to obtain permissions and construct new transmission capacity. Squaring the circle of providing investment guarantees for transmission capacity, prior to knowledge on which offshore wind projects will proceed is also a source of delay for initiating work on reinforcements.

11.3 Scandinavia

The Danish power system is split into two synchronous zones. In times of low load offshore wind farms connected to the transmission system in the western part of the country together with wind energy onshore add to the power generation in the north of Germany. Power from offshore wind farms connected to the transmission system in the eastern part is injected into the Nordel synchronous zone. The Nordel synchronous zone is characterized by a large amount of hydro power. Hydro power plants can be controlled very fast and they could complement the slower-controllable thermal-dominated generation in the UCTE system. Technically, they could be used to balance fluctuations from wind power in Western Denmark and Northern Germany. However, this is not realised yet practically due to the present settlement model for the power exchange via the high-voltage DC connections between Western Denmark and the Nordel system [Akhm 05].

In addition, in Sweden offshore wind power will mainly be generated close to the loads, i.e. in the south of the country. Therefore, it has a potential to mitigate congestion of the north south transmission links supplying the south of Sweden with power from the hydro plants in central and northern parts of the country.

11.4 References

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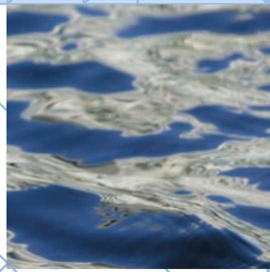


Wind Energy and Trans European Power Exchange

With the exception of Denmark and Northern Germany, wind power generation in the past virtually had no impact on the power system. Wind power was connected to the distribution system in what has been called a "fit-and-forget" procedure.

Today, the fraction of decentralized generation is not anymore negligible. Power system operators have to take decentralized generation into consideration in system planning and dispatch. The application of wind power short-term forecasting and the required supply of a number of ancillary services from large wind farms in several countries show that this phase is currently being approached. The situation would be best described as a "fit-and-react."

When the fraction of decentralized generation is to be further increased as in the case of large offshore wind farms, adapting the traditional power system to the new production units will not anymore be sufficient. In such a situation, decentralized generation must be able to replace traditional generation capacity. Future decentralized generation plants must be fit to the grid and relied upon.

The present chapter looks closer at the trans-national dimension of the grid integration of large decentralized wind farms. The aim is to come to a "fit-and-rely-upon" practice soon rather than to stay on the fit-and-react level.

12.1 Trans-national Dimensions

Power Transmission

Future offshore wind farms of significant installed generation capacity will require connection to the transmission system. There are a number of implications, which have been introduced and discussed on a per-country basis in the previous chapters.

Today, most grid issues like grid codes, the local re-inforcement of transmission lines and the availability of substations are dealt with in each country by TSOs and regulators. The treatment of these subjects is typically determined by national legislation and the grid topology, depending on geographical situation and historical developments.

The subject of energy balancing is also dealt with separately per country or per control area. An additional feature resulting from the internal European market for electricity is the possibility of international trade between market players in the EU member countries. Before the liberalization, cross-border flows were either due to long-term contracts between nationally acting utility companies or due to frequency support from neighbouring countries in case of contingencies within the UCTE

system. The liberalization offers the possibility for trade and hence balancing power on day-ahead and even intra-day markets with additional opportunities for settling fluctuations from large wind farms.

Technically, a functioning market place for electricity presupposes an adequate infrastructure in order to facilitate free trade. Historically, transmission capacity among UCTE countries and even more between the UCTE and other synchronous zones is low. The European Union therefore pursues the development of trans-european networks (TEN) for energy, transport and telecommunication.

> **"The aim of Community action for the development of Energy TENs is to contribute to:**
>
> - **effective operation of the Internal Market in general, and of the Internal Energy Market in particular.**
> - **strengthening Economic and Social Cohesion by reducing the isolation of theless-favoured regions of the Community.**
> - **reinforcing Security of Energy Supply." [TEN 97]**

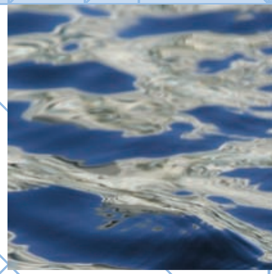
The relevance of trans-european networks for energy (TEN-E) for the large-scale integration of wind energy into the European energy supply was not addressed in the original TEN action. However, in the revision of the TEN-E Guidelines from 2003 the integration of power from wind energy into the European power systems has been clearly acknowledged as an additional driver for the development of European transmission infrastructures.

System Integration of Power from Wind Farms

The spatial dispersion of wind generators leads to an increased capacity credit that may be allocated to wind energy. Expressed in simple words, some wind is always blowing somewhere. While this statement is generally true, it must be noted that spatial smoothing often but not necessarily remains limited when areas are regarded of only a few hundred kilometres in diameter [Soen05]. With the exception of specific microclimates the cross-correlation of wind speeds at sites with a few hundred kilometres distance lies in the range of 0.7 to 0.8 [Dowl 05].

On the other hand, wind speed at sites of more than 1000 km distance is virtually uncorrelated. This is due to the fact that typical weather patterns in Europe are only about 1500 km in extent [Dowl 05]. As indicated in Figure 12-1 the distribution of cyclones and anticyclones over Europe is typically complementary. Additionally, the Mediterranean region is characterized by a number of more localized effects.

Hence, in order to generate a significant share of the European electricity consumption from wind power, continental-wide smoothing effects must be utilized to a maximal extent. For this purpose a good trans-European transmission infrastructure is essential. Firstly, this applies to high-voltage transmission links between countries as they are addressed in the TEN-E action. Secondly, this applies



to offshore transmission links interconnecting different offshore wind farm areas and load centres over long distances. Thirdly, this applies to meshed long distance transmission infrastructures for interconnecting centres of load and generation on a European scale and beyond.

The first application is currently being implemented in the framework of the TEN-E action. The second will be receive increasing attention with increasing distance of wind farms from the shore. The third is currently not considered an economically viable option. The reasons are the high capital costs for HVDC substations, especially offshore, and the lack of a stable political framework for such investments.

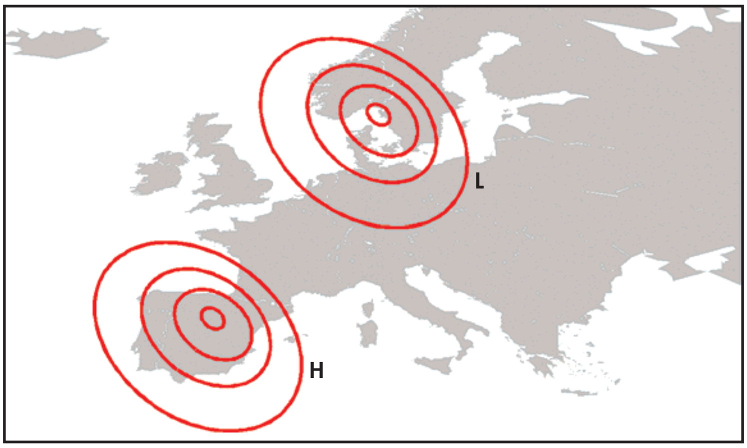


Figure 12-1: Situation of meteorological high- and low pressure systems over Europe (courtesy of A. Garrad, Garrad Hassan)

International Trade

Today in most European countries electricity wholesale happens for the largest part bilaterally. This in particular concerns forward markets where bulk power is typically contracted on an annual or seasonal basis. Additionally, most countries offer some possibility to trade electricity one day ahead on a spot market, typically a power exchange or a day ahead hub. Finally, balancing power could be traded very close to real time on an intra-day market [Meeu05a].

While power transmission within a control area is regarded as a technical responsibility of the TSO, the allocation of capacity for cross-border transmission is organized differently. Currently, the allocation of cross-border capacity happens in an uncoordinated way. In most cases it is not market-based. While the European RES-E directive [RES-E 01] suggests priority dispatch for renewables to be implemented in the national regulatory frameworks, there is no such notion as priority allocation of cross-border capacity for electricity from renewables. According to the principles of the internal electricity market this allocation should be market-based. If wind power is to play an important role in the internal European electricity market, tools for short-term as well as seasonal predictions for wind farm output are essential.

The quality of short-term predictions increases with decreasing prediction horizon. Therefore, wind power should be traded on power markets as close to real time as possible. As a consequence, in the

absence of priority allocation of transmission rights for electricity from renewables, transmission rights would need to be allocated as close to real time as possible in order to facilitate the international trade of electricity from wind farms or at least the predictable part of wind energy production.

The allocation of cross-border capacity for trade close to real time would be possible by linking the member states' day-ahead and intra-day markets for electricity as indicated in Figure 12-2. This means that a part of the available transfer capacity would be allocated to power exchanges and intra-day markets. Power exchanges of different control areas could then use this capacity as an instrument for equalizing their national markets (Stage 1). In the following step, also intra-day markets could be coupled by allocating cross-border capacity to them making power from different control areas available for balancing (Stage 2). The results would be equalized market prices at neighbouring markets and generally a lower volatility. For the international trade of wind power it is essential to make this market coupling mechanisms available as close as possible to real time.

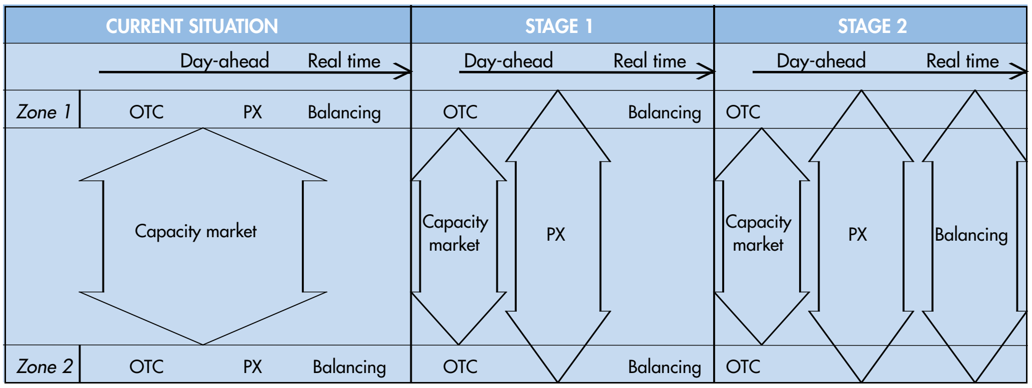


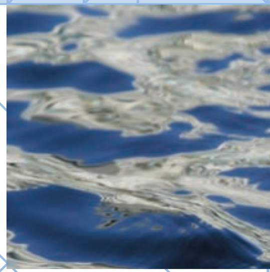
Figure 12-2: Stages towards improved linkage of European member state wholesale markets and balancing markets, from [Meeu05b]

12.2 Terminology

For the evaluation of power transmission constraints between countries, a clear and precise terminology is needed. Here we sum up the major concepts with reference to the definitions of transfer capacities by the European Transmission System Operators (ETSO) [ETSO 01].

With regard to the cross border exchange of electricity the differentiation between physical power flows and commercial exchange is crucial.

The physical flow is determined by the grid topology and the power sources and sinks. The physical cross-border flow between neighbouring countries is the sum of power flows on all interconnecting transmission lines. It can be measured and calculated by a power flow simulation.



The commercial exchange of power is defined by the commercial and contractual relationships between producers, traders and consumers. Commercial exchange capacities available for trade must be published before real time to give traders the time to use the information [ETSO 04].

The commercially used terms for exchange capacity as defined by ETSO [ETSO 01] are:

"The Total Transfer Capacity TTC, that is the maximum exchange programme between two areas compatible with operational security standards applicable at each system if future network conditions, generation and load patterns were perfectly known in advance."

"The Transmission Reliability Margin TRM which is a security margin that copes with uncertainties on the computed TTC values arising from:

a) Unintended deviations of physical flows during operation due to the physical functioning of load-frequency regulation

b) Emergency exchanges between TSOs to cope with unexpected unbalanced situations in real time

c) Inaccuracies, e. g. in data collection and measurements"

"The Net Transfer Capacity NTC that is defined as:

$$NTC = TTC - TRM$$

NTC is the maximum exchange programme between two areas compatible with security standards applicable in both areas and taking into account the technical uncertainties on future network conditions."

Hence, in first instance, the NTC is the capacity available for commercial cross-border exchange. These capacity values can vary in time depending on the status of the different power systems during capacity planning. One may additionally distinguish capacity values reflecting capacity available or already allocated between different allocation phases [ETSO 01]:

"The Already Allocated Capacity AAC, that is the total amount of allocated transmission rights, whether they are capacity or exchange programmes depending on the allocation method."

"The Available Transmission Capacity ATC, that is the part of NTC that remains available, after each phase of the allocation procedure, for further commercial activity. ATC is given by the following equation:

$$ATC = NTC - AAC$$ **"**

The different definitions of different capacity values are illustrated in Figure 12-3. **(see next page)**

The different definitions of different capacity values are illustrated in Figure 12-3.

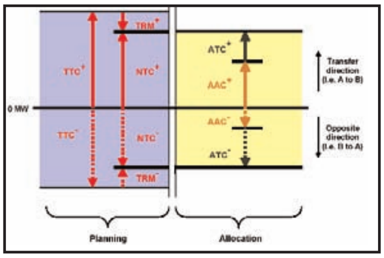


Figure 12-3: Illustration of transfer capacity definitions [ETSO 01]

In the current circumstances, the allocation of cross-border capacity happens in the framework of long-term contracts or on markets for cross-border capacity. While the European RES-E directive suggests priority dispatch for renewables to be implemented in the national regulatory frameworks, there is no such notion as priority allocation of cross-border capacity for electricity from renewables. Hence, wind power has to compete for cross border transmission capacity in the markets.

12.3 Net Transfer Capacities between Participating Countries

All TSOs of COD participating countries are members of ETSO. ETSO publishes indicative values for net transfer capacity between its members' transmission systems. The countries whose TSOs are ETSO members are shown in Figure 12-4.

Figure 12-4: Map of Europe with control areas of ETSO members in blue [ETSO 05]

Characteristic values for the NTC are typically published twice a year, namely, for peak hours at a working day in winter and in summer. Annex 1 contains NTC values between COD participating countries and their neighbours. A complete overview of NTCs for all boundaries between ETSO members is provided as tables and as a map at the web site of ETSO http://www.etso-net.org/ [ETSO 05]. This web site is also updated regularly.

A number of general observations can be made based on the NTC data from 2004 and 2005:

- Total import and export capacity of a country is not necessarily equal to the sum of the net transfer capacity over all its borders.
- Total NTC values for import and export have to be interpreted with care when control areas experience high transit power flows. Especially in the BeNeLux region congestion often occurs due to high transit flows.
- Transfer capacities are generally high between members of the UCTE while they are often low between members of different synchronous zones. Historically, the creation and interconnection of synchronous zones was to a great extent driven by the geographical situation. The different synchronous zones are typically separated by seas and linked by a few high voltage DC connectors of limited transmission capacity.

- Denmark, on the one hand, has relatively high net transfer capacities regarding the size of its two control areas. On the other hand, Denmark functions as a bridge between the Nordel synchronous zone and the UCTE, which may lead to high transit flows. Additionally, Denmark has a high share of wind power already. Higher net transfer capacities between Nordel and UCTE would therefore be useful in any case.

- Poland, currently being the only former Eastern Block country within the COD, has only very limited import capacity and a high wind energy potential.

- Transmission bottlenecks within the UCTE exist at the northern borders of Spain and Italy and on the Balkan. These are not directly related to the grid integration of offshore wind energy in the Baltic and the North Sea states. However, with regard to a long-term strategy that would allow the trans-continental balancing of power from wind energy in function of the Europe-wide complementarity of wind speeds, these transmission links are crucial. Strong transmission lines connecting Western and Central Europe to the Mediterranean Countries are a first necessary condition in a long-term strategy for the transcontinental exchange of wind power.

These findings are in line with the European TEN-E action. There, nine axes for transmission reinforcement have been identified (Figure 12-5) including

- reinforcement of transmission lines in the BeNeLux region, France and Germany (EL 1),

- reinforcement of connectors from Central and Western Europe to the Balkan the Mediterranean states and Portugal (EL 2, EL 3, EL 4),

- increase of transmission capacity between UCTE system, Great Britain and Ireland (EL 5, EL 6),

- creation of a Baltic transmission ring (EL7),

- increase of transmission capacity between Germany and Austria and the new Central European member states of the EU-25 (EL 8),

- creation of a Mediterranean transmission ring connecting Southern Europe to Northern Africa and the Near East (EL 9) [TEN 05].

The main developments on international interconnections within and at the frontiers of the UCTE system have been identified in detail in the UCTE System Adequacy Forecast 2005 – 2015 [UCTE 05].

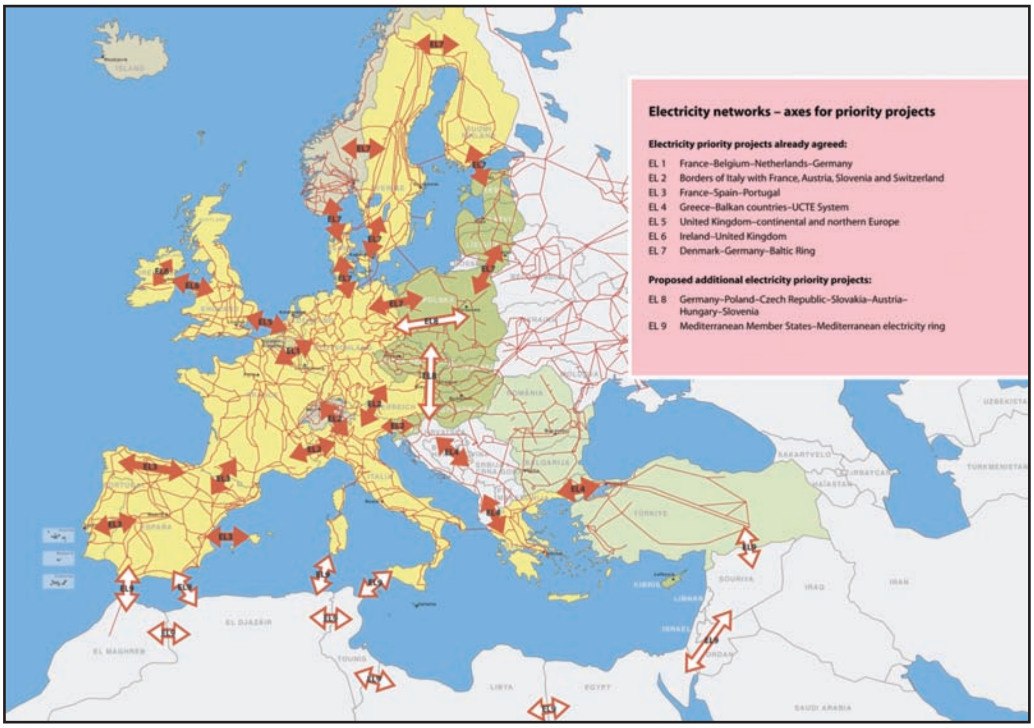


Figure 12-5: Axes for priority projects for electricity transmission in Europe [TEN 05]

In the proposed revision of the TEN-E Guidelines [TEN 03], the integration of offshore wind energy has been mentioned as one rationale for the definition of the priority axes EL 5, EL 6 and EL 7 regarding the North Sea and Baltic Sea regions. The need of strong trans-continental transmission lines for the grid integration and balancing of power from large wind farms has not been included in the revision of the TEN-E Guidelines.

The proposed revision of the TEN-E Guidelines were also subject to public consultation. The only major comment related to the grid integration of wind farms came from UCTE pointing at the issue of balancing power from wind energy and the need of increased reserve margins between UCTE members due to wind energy.

12.4 Transnational Offshore Grids

The reinforcement of existing transmission lines and the building of new lines is one action in order to increase the fraction of wind power in the European power systems. One further step with regard to the transportation of power from offshore wind farms to load centres all over Europe is the development of Europe-wide offshore grids and transeuropean overlay grids.

The use and implementation of offshore grids has been studied by several authors [Dowl 04, Czisch 04, Wats 02]. While [Wats 02] looks at a limited grid in the Irish Sea, [Dowl 04] and [Czisch 04] propose some kind of trans-European meta grids. Figure 12-6 shows such a meta grid structure that could be used to collect energy from offshore wind farms as proposed in [Dowl 04]. Czisch [Czisch 04] goes a step further and develops a vision of an overlay grid connecting Northern Africa, Europe and the Middle East (Figure 12-7).

Figure 12-6: Possible first stage of a transnational offshore grid [Shaw 02]

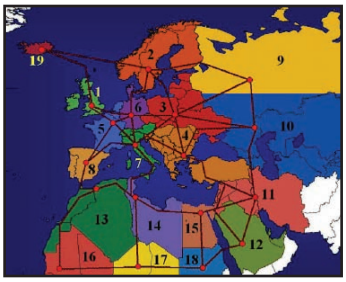


Figure 12-7: Schematic representation of potential electricity transmission paths for an intercontinental overlay transmission system [Czisch 04]

Scenarios like those proposed in [Dowl 04] and [Czisch 04] require high investment costs for the grid infrastructure. Nevertheless, the authors introduce them as economically most interesting long-term options (several decades) for an energy economy based on renewable sources with a very large wind power fraction.

Studies of offshore transmission grids on a short and mid term are more sceptical. The option of interconnecting offshore wind farms via meshed offshore grids has been studied for the UK, the Netherlands and Germany [DTI 05, PBPo 02, Derk 04, Dena 05].

The clustering of wind farms to a limited number of offshore substations is therefore considered as an option for the reduction of connection costs. Moreover, this approach is necessary where coastal crossings should be avoided as much as possible for reasons of environmental protection or sea defence. Therefore, from the spatial planning point of view shared connections to clusters of offshore wind farms should be promoted as much as possible. Moreover, in the German Dena report [Dena 05] HVDC overlay lines onshore are considered for transporting offshore wind power to the load centres in the country after 2015. However, as long as connections to substations on shore are possible, it is not anticipated that clustered offshore parks will become interconnected to long-distance or even meshed transmission grid infrastructures off shore.

12.5 Conclusions and Recommendations

The spatial dispersion of wind generators leads to an increased capacity credit for wind energy and to improved short-term predictions for spatially dispersed clusters of wind farms. This spatial smoothing effect is limited within relatively small areas but it is large when the area of interest is of the size of a weather system. In order to utilize these effects, the transmission system must be able to transfer

sufficiently high amounts of power over the continent and market mechanisms must be developed enabling international trade as close as possible to real time.

The definitions of transfer capacity for cross-border exchange have been reviewed and current transfer capacities between the COD participants and their neighbours are given in Annex 1 based on data published by ETSO. From these data, transmission bottlenecks can be identified between the different European synchronous zones, between Western Europe and the former eastern block countries, and between Central and Western Europe and the Mediterranean region. These main bottlenecks correspond to a large extent to the priority axes defined in the European TEN-E action.

In order to facilitate the transcontinental exchange of electricity from wind power, grid reinforcements in line with the TEN-E priority axes are essential. In the long run, overlay grids and offshore grids for long-distance power transmission may become necessary in order to facilitate the intercontinental transfer of electricity from renewable sources.

Today, the development of offshore grids is not competitive in comparison to the reinforcement and extension of existing infrastructures on shore. Nevertheless, policy makers should not lose such scenarios out of mind.

Where smaller and cheaper infrastructures are necessary and sufficient in order to collect power locally off shore for minimizing the cable costs and the number of coastal crossings, governments and regulators should actively steer these developments.

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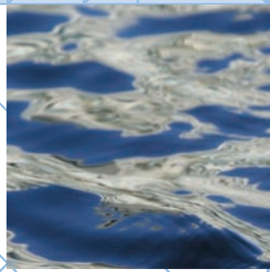

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Conclusion

13.1 Approach

A number of issues affecting the grid integration of offshore wind energy have been identified. Some of them are emphasized more or less in different countries depending on characteristic properties of the different power systems (Continental Europe, British Isles, Skandinavia). However, most identified issues are in different ways common to all participating countries. These issues are:

- grid reinforcement,
- requirements from grid codes,
- offshore cables,
- grid access, pricing and balancing,
- Trans European power exchange.

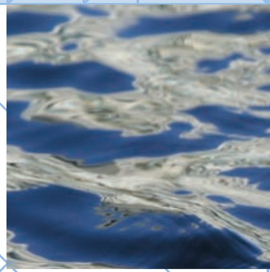
Based on the information gathered in this report, conclusions are drawn for each of these issues. Based on the conclusions, the COD working group has compiled a set of observations and recommendations as well as its expectations for future developments. Some of these issues have already been addressed in the declaration of the EU policy workshop about the development of offshore wind energy in Egmont aan Zee (Netherlands) in October 2004 [Egmo 04].

13.2 Conclusions and Recommendations

Grid Reinforcement

There is no doubt that considerable grid reinforcements will become necessary in all participating countries in the coming five to ten years, if aspirations for offshore wind energy are to be met. These reinforcements can take 10 to 15 years due to the long lead times for land acquisition and permits. Although the necessary reinforcements have been documented in some countries, no TSO is preparing the necessary reinforcements in practice.

For a developer, a guarantee for consent of a project, and availability of a timely grid connection, are necessary pre-condition to ordering and financially backing substantial grid reinforcements. However, in accordance with national legislation, TSOs will initiate planning procedures for grid reinforcement only when the reinforcement has been ordered by the developer. Reinforcement must be initiated early in the development process, and is subject to uncertainty. Hence, developers and TSOs are caught in an impasse.



The large-scale deployment of offshore wind energy requires grid reinforcement. The longer this is postponed the more the deployment of offshore wind energy will be retarded. In some cases where a timely grid reinforcement can not be expected, innovative alternatives may be applicable in order to facilitate the grid connection of a wind farm. Such alternatives are dynamic line ratings and high-voltage DC transmission links on shore.

The need to provide early funds for strategic infrastructure is not new, and has previously simply been funded by governments. Under the now liberalised market frameworks, governments should consider ways of removing the impasse between TSOs and developers. Approaches which have been considered and / or used in different EU member states include: government backing up investment made by TSOs until such time as it is utilized; use of European funds to provide strategic infrastructure; or sharing investment risk across electricity market participants.

Grid Codes

Grid codes list the power system operators' requirements for grid connection of plant to the transmission or distribution system – with different requirements and / or parameters for each. Large offshore wind farms will tend to connect increasingly to the transmission system, as opposed to typical European onshore wind farms which tend to be distributed plant.

In all participating countries there is a general trend towards the requirement of active control of large wind farms: the wind farm has to contribute actively to the stability of the power system. In detail, the requirements in the different countries differ significantly regarding the specified set-points for the various control actions, and also in terms of the required capabilities.

Active control typically includes the possibility for the TSO to curtail the wind farm's power output when the grid stability is at risk. This possibility can interfere with the requirement for priority dispatch of electricity from renewable sources, but can also result in more efficient use of existing infrastructure. Power curtailment should only be a temporary measure in order to cover the time period until new infrastructure is built. Since the curtailment of wind farm output power should affect only small amounts of energy, this conflict of interest can probably be solved relatively easily either on a contractual or on a regulatory basis.

In general, curtailment of wind farm output should not be seen as a barrier to priority dispatch. As it has zero fuel costs, wind energy plant should be curtailed only when necessary for stability of the system and if possible only until the necessary infrastructure is built.

The set points required by a TSO typically reflect the circumstances in a given power system. Wind turbine manufacturers find it difficult to adapt the control capabilities of their machines to a number of different sets of requirements in different countries. Therefore, the required control capabilities for large wind farms should be harmonized all over Europe while the specific set-points should also in future be determined by the TSO responsible for the specific power system.

Common Offshore Cables

Studies carried out in different countries show that bundling of offshore cables from several wind farms offshore is beneficial. A multitude of cable ducts crossing the coastal areas and dykes can negatively affect the ecosystem and deteriorate the protection of the coast line. In contrast, the connection of several wind farms via a common cable or cable duct to the connection point onshore contributes to streamlining the procedure for grid connection. Via such a common cable connection the effective grid connection point would likely be situated offshore. In some cases, the bundling of offshore cables can save costs for the cable duct.

Although these advantages are well known, offshore transmission cables from different wind farms are currently not bundled. Although it has been considered, discussions tend to be mired in commercial and regulatory issues. There is a lack of true strategic planning or legal provisions to impose planning of offshore transmission infrastructures in the different countries.

Finally, the bundling of offshore wind farms would lead to radial offshore grid infrastructures. These would be spatially limited in the beginning but they could become the initial nodes of an international offshore grid to emerge by stepwise interconnection.

In order to kick off the development of common infrastructure, its facilitation should be considered in the national and international regulatory framework.

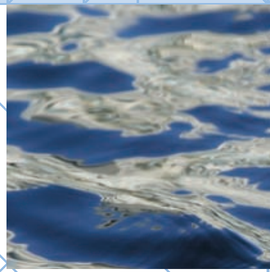
Grid Access, Pricing and Balancing

According to Article 7 of the European RES-E directive, electricity from renewable sources may receive priority access to the power system, and priority dispatch insofar as the operation of the national power system permits. Respective laws have been introduced in most participating countries; however, the implementation of these requirements into national law is different in each country.

In practice, the decisive factor, besides the physical access to the grid, is the price for electricity from renewable sources on the electricity markets. Priority access is only useful when market parties are willing (or forced by law) to buy electricity from renewable sources at sufficiently high prices.

Especially in countries where renewables are supported via tradable certificates, the revenues for electricity from wind energy depend firstly on the market price for the tradable certificate and secondly on the market value of the remaining brown energy. The certificate value is typically limited by the penalty for unfulfilled quota obligations, and in some countries also by fixed minimum prices. The value of brown energy is determined by the conventional market. Conversely, in countries with fixed feed-in tariffs, the revenues for both brown electricity and green value are determined by law and imposed via the tariff.

Due to the variability of wind energy, this electricity price can be relatively low, especially in countries where imbalance is penalized. In order to increase the market value of energy from large wind farms,



good short-term predictions are necessary, possibly in combination with concepts of adapted demand control, back-up generation or storage. Therefore, in order to improve the value of wind-generated electricity, short-term forecasting of output should be supported and developed.

In addition, market arrangements which penalise imbalances should reflect the real cost of imbalance. In some countries imbalance prices are disproportionally high in order to prevent market parties from speculation. However, such high imbalance prices penalize decentralized generation.

Trans European Power Exchange

Historically, interconnections between countries and their power systems were intended for international support in case of contingencies and, to a limited extent, for bilateral trade based on long-term contracts. With the establishment of the internal European electricity market, an increasing fraction of the available capacity is now used for international trade. This latter capacity is mainly traded bilaterally, and not explicitly used for the levelling of power fluctuations introduced by wind energy.

In order to enable wind energy to contribute significantly to power supply all over Europe, the spatial variation of wind power needs to be utilized to the maximum possible extent. Because weather systems can span whole regions at a time, this implies power flows between synchronous zones, and within the UCTE – in particular between the main block and the Southern European countries. To supplement the technical infrastructure, market mechanisms need to be developed enabling international trades as close as possible to real time, to facilitate programmed transfers of wind energy.

Currently transmission capacity between these regions is limited, and it is an objective to reinforce the power system, especially according to a number of priority axes as defined in the European TEN-E action. However, the current version of the TEN-E action sees the importance of cross border transmission capacity for the grid integration of wind energy mainly in the very regions where large increases in wind energy deployment are anticipated. The importance of transcontinental transmission to benefit from the spatial dimensions of meteorological phenomena has not yet been acknowledged. This should be taken into account in the next revision of the TEN-E action.

Transcontinental offshore transmission and overlay grids have been proposed as the most economic measures to increase the share of wind power and other renewable sources that the European power systems can absorb. However, in practice most actors still perceive these concepts as not competitive solutions onshore in the short and medium-term. Possibly, spatially limited radial offshore grids could form the initial nodes of such a grid.

13.3 Overall Conclusion

On a technical level, a number of bottlenecks for the large-scale grid integration of offshore wind energy exist and much needs to be done to remove them. The necessary measures have been identified in previous studies for the specific national contexts. The European Concerted Action for Offshore Wind Energy Deployment (COD) has inventoried the situation in the participating countries and analyzed the future requirements on a European background.

All measures required in order to render the large-scale integration of offshore wind energy in Europe possible are technically known. Therefore, the feasibility of integrating large amounts of offshore wind power in the considered time frame does not pose a technical problem. The barriers to the further integration of offshore wind energy are mainly a question of finance and hence based on political decisions and the creation of a favourable framework.

In practice the removal of barriers to the grid integration of offshore wind energy requires political commitment of governments, a suited regulatory framework and the active participation of TSOs. In general, any short-term solution should fit into a long-term strategic vision.

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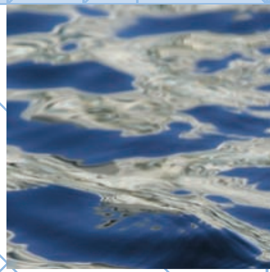

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Annex

Annex 1: Net Transfer Capacities

Annex 2: Key Data for all Participating Countries

Net Transfer Capacities between COD Participants and their Neighbours

Winter 2004 / 2005

Source: ETSO, http://www.etso-net.org/, accessed 28/04/2005

NB: Cross border exchange with one country may affect the available NTC to another country. As a consequence, Total Export and Total Import NTC are not necessarily equal to the sum of all cross-border NTCs.

Synchronous zones:
- UCTE
- Nordel
- Ireland
- Great Britain

NTC [MW] To	From Belgium	Netherlands	Poland	Germany	DK-West	DK-East	Sweden	Ireland	UK	France	Austria	Czech Rep	Switzerland	Slovakia	Finland	Norway
Belgium		2400								2250						
Netherlands	2350			3800												
Poland				2000			550					800		750		
Germany		3000	1100		1200	550	600			2550	1400	2300	4000			
Denmark-West				800			460									1000
Denmark-East				550			1300									
Sweden			200	600	490	1700									1400	3350
Rep. of Ireland									330							
UK								0		2000						
France	2750			5600					2000							
Austria				1600								400/1100	1500			
Czech Rep.			1650	700							600/400			600		
Switzerland				3000						3200	1200		NA			
Slovakia			750									2330/1550				
Finland							1800									70
Norway					950		3050								100	
Total Export	5100	3500	2300	18650	2640	2250	7760	0	2330							
Total Import	4650	4700	750	16700	2260	1850	7740	330	2000							

	Belgium	Denmark	Germany	Republic of Ireland
Plans and Prospects				
Offshore areas	1 area exclusive for offshore wind, north east of the Belgian EEZ, bordering the Dutch EEZ.	West coast of Jutland, South of Lolland, later also Kattegat and Great Belt	North Sea: Borkum, Helgoland, Sylt, open North Sea Baltic Sea: Rostock, Rügen	No exclusive zones for offshore wind energy. Licenses granted mainly at the east coast.
Planned offshore wind power	1.75 GW	830 MW (planned for 2008), 4 GW (aim for 2030)	20.4 GW (41.3 GW beyond 2020); however, development probably slower than expected	1370 MW, potential around 3 GW
Timing	2020	2008/2030	2020	2010
Transmission System				
TSOs	Elia (> 70 kV)	Energinet.dk Western Denmark 400 kV, 150 kV; Eastern Denmark 400 kV, 132 kV	RWE Transportnetz Strom GmbH, E.ON Netz GmbH, Vattenfall Europe Transmission GmbH, EnBW Transportnetze AG	ESB National Grid (will soon become EirGrid plc): 110 kV, 220 kV, 400 kV
Control zones and operators	Elia (entire country)	Western Denmark, Eastern Denmark operator Energinet.dk	One control zone per TSO: RWE Transportnetz Strom GmbH (west), E.ON Netz GmbH (centre), Vattenfall Europe Transmission GmbH (east), EnBW Transportnetze AG (south west, not at the coast),all together: German control block	EirGrid (entire country)
Synchronous Zone	UCTE	Western Denmark: UCTE Eastern Denmark: Nordel	UCTE	Island of Ireland
Final electricity consumption (2002) [TWh]	78.4	32.7	498.8	21.8
Generation capacity (2002) [GW]	15.5	13.3	125.0	5.4
Peak load (2002) [GW]	13.692	Western Denmark: 3.68 Eastern Denmark: 2.68	74 (2003)	4.24
Minimum load (2002) [GW]	6	Western Denmark: 1.19 Eastern Denmark: 0.83	38 (2003)	1.50
Power Generation Portfolio [GW]				
Nuclear	5.76	0.00	23.40	0.00
Thermal (non-nuclear)	8.34	10.40	81.09	4.76
Hydro	1.41	0.01	8.48	0.53
Wind	0.03	2.89	12.00	0.14
others	0.00	0.00	0.00	0.00
Wind in 12/2004 [GW]	0.10	3.12	16.63	0.34
Offshore Power Injection				
Suited Substations	Slijkens, Zeebrugge (Koksijde not considered)	Western Denmark: Karlsgarde (Horns Rev A, 150 kV), Idomlund, Endrup, Kasso, Nordjyllandsvaerket (all 400 kV) Eastern Denmark: Radsted, Vestlolland, Stignaesvaerket (132 kV)	North Sea: Böxlund, Brunsbüttel (Vattenfall E.), Brunsbüttel (E.ON), (areas Sylt, Helgoland), Maade, Emden/Borssum, Diele, (area Borkum) Brunsbüttel (Vattenfall E.), (Conneforde, Moorriem in 2020), (open North Sea area) Baltic Sea: Bentwisch (area Rostock), Lubmin (area Rügen)	East coast (220 kV substations): Finglas, Arklow, Great Island 110 kV substations: many along the coast
Substation Voltage today	each 150 kV	Karlsgade 150 kV (Horns Rev A), Radsted 132 kV (Rodsand)	all 380 kV, with exception of Maade, Emden/Borssum: 220 kV	110 kV, 220 kV
Offshore power limit	350 MW (Slijkens), 300 MW (Zeebrugge)	no limits specified	after installation of phase shifters at substations Brunsbüttel and Diele, extensions of several existing lines inland, extension of substations (inland), provision of capacitors (inland): 476 MW offshore (2007 scenario) could be connected as scheduled but need to be curtailed at high wind/low load	250 MW per 220 kV substation
Grid Issues				
Grid code requirements	Power quality, power control not required but power curtailment, frequency control not required, voltage control (reactive power) voltage and frequency ride through.	Power quality, extensive functionalities for active power control including frequency, voltage control (reactive power) voltage and frequency ride through, external control and monitoring.	Power quality, power control not required but power curtailment, frequency control not required, voltage control (reactive power) voltage and frequency ride through.	Power quality, power control, power curtailment, frequency control, voltage control (reactive power) voltage and frequency ride through.

Balancing	Elia via responsible parties, with penalties	Energinet.dk per control zone	Via TSO per control zone, no penalties for unbalance	EirGrid, no penalties for unbalance; short-term predictions oblogatory for wind farms above 30 MW
Transmission bottlenecks	At injection points and around the Brugge area (all 150 kV)	Western Denmark: Capacity of Lykkegard-Idomlund connection at west coast of Jutland, interconnector capacity with Northern Germany Eastern Denmark: the 132 kV system in the south of Eastern Denmark is generally weak for connection of large amonts of production capacity	generally: bottlenecks for power transmission from the rural Baltic and North Sea regions to the load centres: Rhein/Ruhr, Frankfurt, Stuttgart, München	Reinforcements will be taken care of when necessary.
Necessary reinforcements	extending two times 400 kV to the coastal substations	Western Denmark: a number of reinforcements are planned, not specifically related to offshore wind energy (until 2008), 400 kV connection Idomlund-Endrup (2009-2012) Eastern Denmark: 400 kV ring connecting Stignaesvaerket, Rislev (or alternatively Herslev), Radsted, Vestjolland would facilitate large scale connection in Lolland/Falster/South of Zealand	For 2020 scenario: many extensions, reinforcemens, new lines. Especially: 2 HVDC lines of a total 1050 km to the South west and South	not specific to offshore wind power
Timing of reinforcements	to be published in September 2005	Reinforcements necessary for connection of Horns Rev B and Rodsand B until 2008, new 400 kV lines partly envisaged until 2012, partly not specified	by 2007 only reinforcements or extensions of existing systems, no new lines; subsequenlty also new lines for 20 GW offshore in 2020	Forecast statement until 2011 is just available.
External Factors				
Import/export/transit	transit Fr -- NL affects congestion inland	Transit from Norway flows via Western Denmark, related reinforcements are scheduled for 2008/20012; reinforcement also required in Noerthern Germany	Power transit from Scandinavia leads to congestion in the North already today	Power exchange with Northern Ireland; HVDC interconnector Ireland-Wales is under discussion. Not related to offshore wind power.
other factors	NorNed connector may affect Dutch import from Be, future of power plant and industry in Gent	Great Belt interconnector between Western and Eastern Denmark in discussion for 2009-2012. This together with an additional Oresund cable to Sweden would affect capacity for cross-border exchange.		Interconnector Ireland - Wales under discussion.
Offshore Cable				
Connection, first projects	HVAC 150 kV	HVAC Horns Rev 150 kV Rodsand 132 kV		
Landing, first projects	drilling under the dune			
Best option, long term	not yet considered		Assumption: Mainly initially 150 kV, later 220 kV and 400 kV gas insulated cables (GIL) Parks should be clustered in groups of several MW at an offshore substation, substations will be connected to shore via as little as possible GIL routes (2010 to 2020): environmental issue of passing the Wadden Sea (North Sea) and the Bodden Seas (Baltic)	
Connection and energy pricing				
Connection charges for DG	shallow		shallow	deep
Connection charges for offshore wind				
Priority access for renewables	yes	yes	yes, guaranteed by law (Erneuerbare Energien Gesetz)	
Minimum price	In the Belgian RE certificate systems the kWh price is split in green and brown component.107 €/MWh for offshore wind certificates over 20yrs via TSO, no minimum price for brown value.		minimum during minimum 12 yrs at least, calculation of period and precise price according to EEG	Via bidding system, price cap for offshore wind: 8.4 cents.

Netherlands	Poland	Sweden	United Kingdom
Several areas have been studies. Area along the coast of Holland is the most interesting.	No dedicated areas. Most projects concentrated on the centern part of the coast. 2 wind farms with >100 MW planned east of the Gulf of Gdansk.	no exclusive zone for offshore wind, current projects: around the Swedish coast, mainly in the South.	Round 2 areas: North West, Greater Wash, Thames Estuary
> 6 GW	1.5 GW (filed applications & other possibilities)	560 MW, potential 7 GW	1 GW with planning consent 7.2 GW waiting for applications
2020	No time schedule defined. Potentially 150 MW by 2010.	2008	Possibly 2010, more realistic: 3 GW by 2010, 6 GW by 2015
Tennet: 380 kV, 220 kV regional operators: ≤150 kV	PSE-Operator S.A.	Svenska Kraftnät: 220 kV, 400 kV regional operators: ≤130 kV	National Grid Transco (NGT, England and Wales), Scottish & Southern Energy and Scottish Power (Scotland), SONI (Subsidiary of Northern Ireland Electricity)
Tennet (entire country)	PSE-Operator (entire country)	Svenska Kraftnät (entire country)	National Grid Transco (Great Britain), SONI (Northern Ireland)
UCTE	UCTE	Nordel	Great Britain (England & Wales and Scotland), Island of Ireland (Republic and Northern Ireland)
99.7	137.06	131.6	332.7
20.8	34.9	33.2	77.1
15.0	23.86	27.0 (2001) 26.9 (2003)	61.7
N.A.	14.66	9.25	20
0.45	0.00	9.45	12.49
19.64	32.69	6.85	59.66
0.04	2.18	16.57	4.38
0.68	0.06	0.35	0.53
0.00	0.02	0.00	0.00
1.08	0.06	0.44	0.89
Beverwijk, Maasvlakte (Borssele, Eemshaven not considered)	400 kV: ZRC, SLK, DUN 220 kV: DUN, PLC, REC	Many substations along the Swedish coast	North West: 132 kV system is weak; 400 kV substations at Deeside, Capenhurst, Frodsham, Stannah and Heysham. Greater Wash: Many connection points available on the 132 kV system close to the coast, but these will not be suitable for the largest wind farms. 400 kV substations at Grimsby, Killingholme, Spalding, Walpole and Norwich. Thames Estuary: many possible connection points at 132 and 400 kV close to the coast, both west and south of the proposed wind farms.
150 kV at Beverwijk, 380 kV at Maasvlakte	450 kV, 220 kV, 110 kV	70 kV, 130 kV, 220 kV	33kV, 132kV, 400kV (and possibly 275 kV in some cases)
500 MW Beverwijk, 1500 MW Maasvlakte	TSO prepared study on possibilities of interconnection of wind parks to national grid. No specific treatment of offshore wind energy.	limit in a small region 500 MW, for all Sweden > 5 GW	No limit. New transmission capacity can be provided wherever necessary. However, the provision of this infrastructure may well decide the rate at which new offshore wind farms can be connected.
no requirements published, capacitor banks needed at substations, considered subject to further study		Power quality, no power control, power curtailment, no simultaneous shut-down frequency control not required, voltage control (tap-changing transformer), power factor 1, voltage and frequency ride through.	Power quality, power control, power curtailment, frequency control, voltage control (reactive power) voltage and frequency ride through.

Tennet via responsible parties, with penalties	Responsibility of PSE-Operator. No direct participation of wind power producers in the balancing market. Short-term predictions obligatory for wind farms > 50 MW with penalties for deviations. New draft of Energy Law ammendement envisages separate treatment of wind energy.	Svenska Kraftnät with balance providers, with penalties	TSOs are technically responsible for balancing in real time per control zone. All electricity suppliers (wholesalers) are responsible for their portfolio with penalties.
at injection point Beverwijk and many lines inland (380 kV)	N.A.	Transmission bottlenecks for north-south transmission. Load centres are in the south, hydro generation is in the north. Offshore wind power in the south would not lead to increased congestion.	Transmission bottlenecks exist for north-south transmission, mainly affecting onshore wind power in Scotland and offshore wind power in the North West area and Greater Wash to a minor extent.
reinforce all congested 380 kV lines	N.A.	no reinforcements for offshore wind power	North west, above 455 MW will require reinforcements to export power south; Greater Wash, above 1500 MW may require reinforcements; Thames Estuary, no reinforcements required.
between 2012 and 2019	N.A.	no reinforcements for offshore wind power	Reinforcements for 455 MW of offshore wind in the North West and reinforcements 1000 MW of offshore wind power in the Thames Estuary scheduled for 2006/2007. Major reinforcement of north south interconnector beyond 2010.
Export increases probability of congestion	N.A.	Export to UCTE and other Nordel countries, reinforcement of 3 transmission lines scheduled.	Existing HVDC connections: 2000 MW to France, 500 MW to Northern Ireland; BritNed HVDC connector (1320 MW) may contribute to supply the London area.
BritNed HVDC connector (1320 MW), NorNed HVDC connector (700 MW)	N.A.		HVDC interconnector Ireland-Wales is under discussion. Not related to offshore wind power.
HVAC 150 kV	N.A.	Medium voltage AC: 30 kV cable, 30kV or 50 kV substations	Medium voltage AC: 33 kV
drilling under the dune	N.A.		Different techniques including directional drilling and simple excavation. No particular problem with sea defences or environmental protection.
Offshore substation with one single 380 kV cable to the shore	N.A.	not yet considered, depends on where offshore wind farms will be built	Most projects from now on are likely to use 132 kV or higher.
deep and negotiated	negotiated	generally shallow, deep if grid is extended for only one customer	Deep, likely to move to shallow charging
	No differences between DG and offshore wind envisaged	Offshore cable by an independent TSO and billed to the developer.	Shallow, however, project developers have to pay for substation reinforcements.
	Theoretically - yes	not mentioned in the legislation	none
	No minimum price. Envisaged by the New Energy Law (not yet in force).	No minimum price. Support is via elctricity certificates.	No minimum price. Tradeable certificates with a market size specified by Government.

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NOTICE TO THE READER

Extensive information on the European Union is available through the EUROPA service at internet website address http://europa.eu.int/

The overall objective of the European Union's energy policy is to help ensure a sustainable energy system for Europe's citizens and businesses, by supporting and promoting secure energy supplies of high service quality at competitive prices and in an environmentally compatible way. European Commission DGXVII initiates, coordinates and manages energy policy actions at transnational level in the fields of solid fuels, oil & gas, electricity, nuclear energy, renewable energy sources and the efficient use of energy. The most important actions concern maintaining and enhancing security of energy supply and international cooperation, strengthening the integrity of energy markets and promoting sustainable development in the energy field.

A central policy instrument is its support and promotion of energy research, technological development and demonstration (RTD), principally through the ENERGIE sub-programme (jointly managed with DGXII) within the theme "Energy, Environment & Sustainable Development" under the European Union's Fifth Framework Programme for RTD. This contributes to sustainable development by focusing on key activities crucial for social well-being and economic competitiveness in Europe.

Other DGXVII managed programmes such as SAVE, ALTENER and SYNERGY focus on accelerating the market uptake of cleaner and more efficient energy systems through legal, administrative, promotional and structural change measures on a trans-regional basis. As part of the wider Energy Framework Programme, they logically complement and reinforce the impacts of ENERGIE.

The internet website address for the Fifth Framework Programme is
http://www.cordis.lu/fp5/home.html

Further information on DGXVII activities is available at the internet website address
http://europa.eu.int/en/comm/dg17/dg17home.htm

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