Case Study:
European Offshore Wind Farms
- A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms -

Executive Summary

Project: POWER - Pushing Offshore Windenergy Regions
Client: Der Senator für Bau, Umwelt und Verkehr, Hansestadt Bremen

Authors:
Gerhard Gerdes (Deutsche WindGuard GmbH),
Albrecht Tiedemann (Deutsche Energie-Agentur GmbH (dena)),
drs. Sjoerd Zeelenberg (University of Groningen, Faculty of Spatial Planning)

EXECUTIVE SUMMARY – LESSONS LEARNT

The purpose of the Case Study of European Offshore Wind Farms is to gather and evaluate experiences and lessons learnt from planning and development procedures from eight offshore wind farms in Belgium, Denmark, Germany, Great Britain and the Netherlands. The main objective is to derive information and recommendations for future wind farm projects. The results will be made available to developers, planners and operators, as well as to national and European authorities.

The research work was carried out jointly by Deutsche WindGuard GmbH, the German Energy Agency GmbH (dena) and the University of Groningen (Faculty of Spatial Sciences). It is a sub-project within the EU funded project “Pushing Offshore Wind Energy Region (POWER)”. The case study was carried out on behalf of the Senator for Construction, Environment and Transport of the German State of Bremen.

The German Energy Agency analysed three of the eight wind farms, Nysted, Denmark, and Scroby Sands and Greater Gabbard, both in the United Kingdom; the University of Groningen examined the facility at Egmond aan Zee, the Netherlands; and the Deutsche WindGuard GmbH studied the wind farms at Horns Rev, Denmark, Borkum West, Germany, Butendiek, Germany and Thornton Bank, Belgium. These projects were chosen because they cover a wide range of conditions: online/ planned, and long distance to shore/ near shore, as well as the different national frameworks.

The planning and construction of offshore wind farms is quite different from the development procedure for onshore wind farms. New experiences will have to be gained. The planning of an offshore wind farm is nearly as complex as a conventional power plant. The combination of electrical power generation and offshore technology is quite new and challenging.

The main message from interviews and discussions with offshore wind farm developers, relevant ministries and engineering companies is that the planning for procurement, installation, commissioning and operation is ambitious. The procedures can be improved. In the following, the main conclusions are summarised.

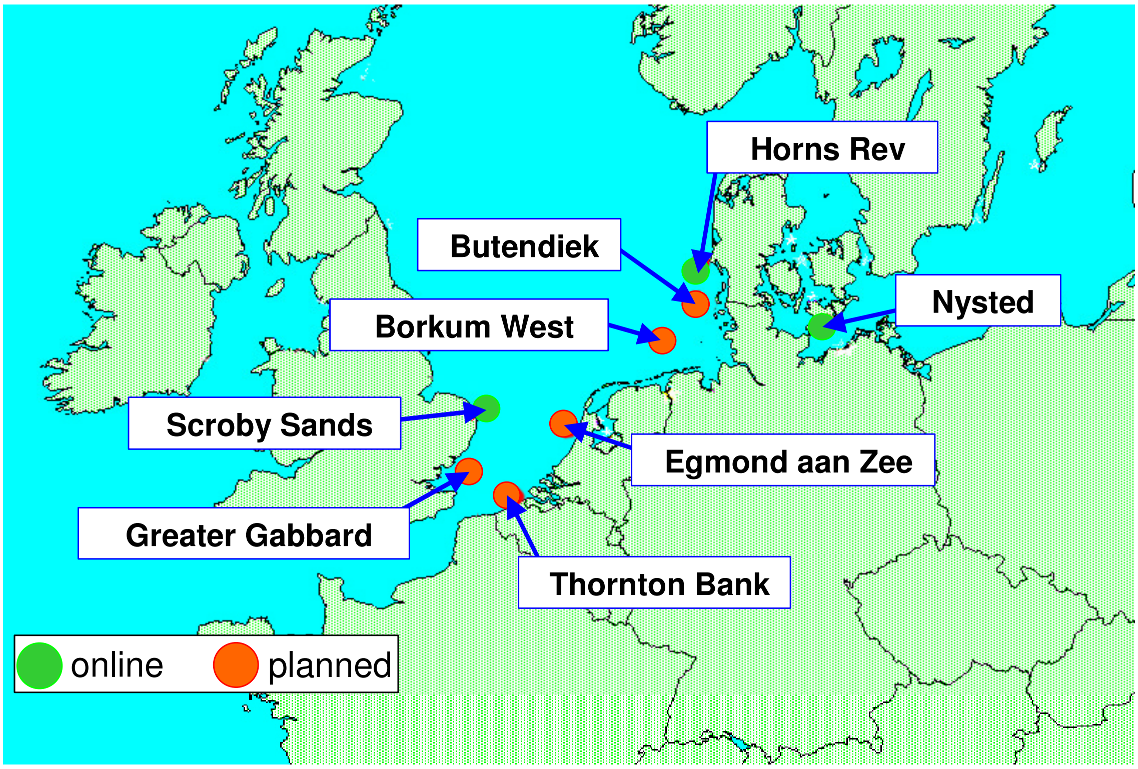

Figure 1: Locations of analysed Offshore Wind Farms

1. The main steps in the planning and realisation of offshore wind farms

From the information gathered, seven main steps could be identified for the planning and realisation of offshore wind farms:

- Pre-project planning,
- Detailed project planning,
- Engineering, testing, production and procurement,
- Installation and commissioning,
- Full operation,
- Repowering and
- Dismantling.

Each of these phases consists of several important work packages, summarised in Table 1. To be successful, the project management must take these work packages into account. The logical work flow of the project is shown in Figure 2, with an overview of the connections between the main phases. This flow chart shows one possibility for the planning and realisation of offshore wind farms.

Table 1: Important work packages during the main phases of offshore wind farm planning and realisation.

<table>
<tr><th colspan="2">Pre-Project Planning</th></tr>
<tr><td colspan="2">Pre-feasibility study (wind farm technology, grid connection and technology, stakeholder involvement, embedding in spatial planning, supply chain management, logistics, economic assessment of main supplies and construction works, environmental and public impacts)
Development of strategies (financing, media, stakeholder involvement, approval) and project structure</td></tr>
<tr><th colspan="2">Detailed Project Planning</th></tr>
<tr><td>Project approval procedure</td><td>Wind farm
Grid connection
Where necessary: grid extension and reinforcement (or appropriate measures e.g. wind energy production management)</td></tr>
<tr><td>Site investigation</td><td>Geographical, wind speed and wind direction, oceanographical, chemical, geological and biological</td></tr>
<tr><td>Definition of functional requirements of main elements of the wind farm</td><td>Wind farm infrastructure
Electrical infrastructure
Harbour logistics
Offshore logistics
Health, safety and environment</td></tr>
<tr><td>Planning of internal controlling system and master plan</td><td>Key performance indicators
Quality assurance and control
Factory acceptance tests
Reporting system
Interface management</td></tr>
<tr><td>Tender process</td><td>Preparation of documents, elaboration of proposals, tender evaluation and sub-contractors' negotiation</td></tr>
<tr><td>Others</td><td>Master Plan (comprehensive plan that describes and maps the overall development concept of the project), financing and insurance arrangements, contracting</td></tr>
<tr><th colspan="2">Engineering, Testing, Production and Procurement</th></tr>
<tr><td>Engineering and planning</td><td>Pre-testing
Installation
Commissioning
Operation, and
Dismantling</td></tr>
<tr><td>Pre-testing and training</td><td>Testing of full size model of wind turbine
Service and maintenance of main components (pile, nacelle, blade, generator, transformer)
Access to wind turbine, and
Training courses for personnel</td></tr>
<tr><td>Production and procurement</td><td>Production of wind farm elements
Interface and work flow management
Quality assurance and control
Factory acceptance tests, and
Transport to logistical centre</td></tr>
<tr><th colspan="2">Installation and Commissioning</th></tr>
<tr><td colspan="2">Site preparation, pre-assembly of parts in harbour, installation of foundation for wind turbines and transformer station
Installation of groups of wind turbines (installation of piles, nacelles and blades, inter-array cable laying and testing)
Installation of electrical infrastructure offshore and onshore (transformer station, cable to shore laying and grid connection infrastructure to public energy supply)
Commissioning of supervisory control and data acquisition system (SCADA), final testing of wind farm, environmental monitoring of construction phase</td></tr>
<tr><th colspan="2">Full Operation</th></tr>
<tr><td colspan="2">Service and maintenance
Environmental monitoring of operation phase</td></tr>
<tr><th>Repowering</th><th>Dismantling</th></tr>
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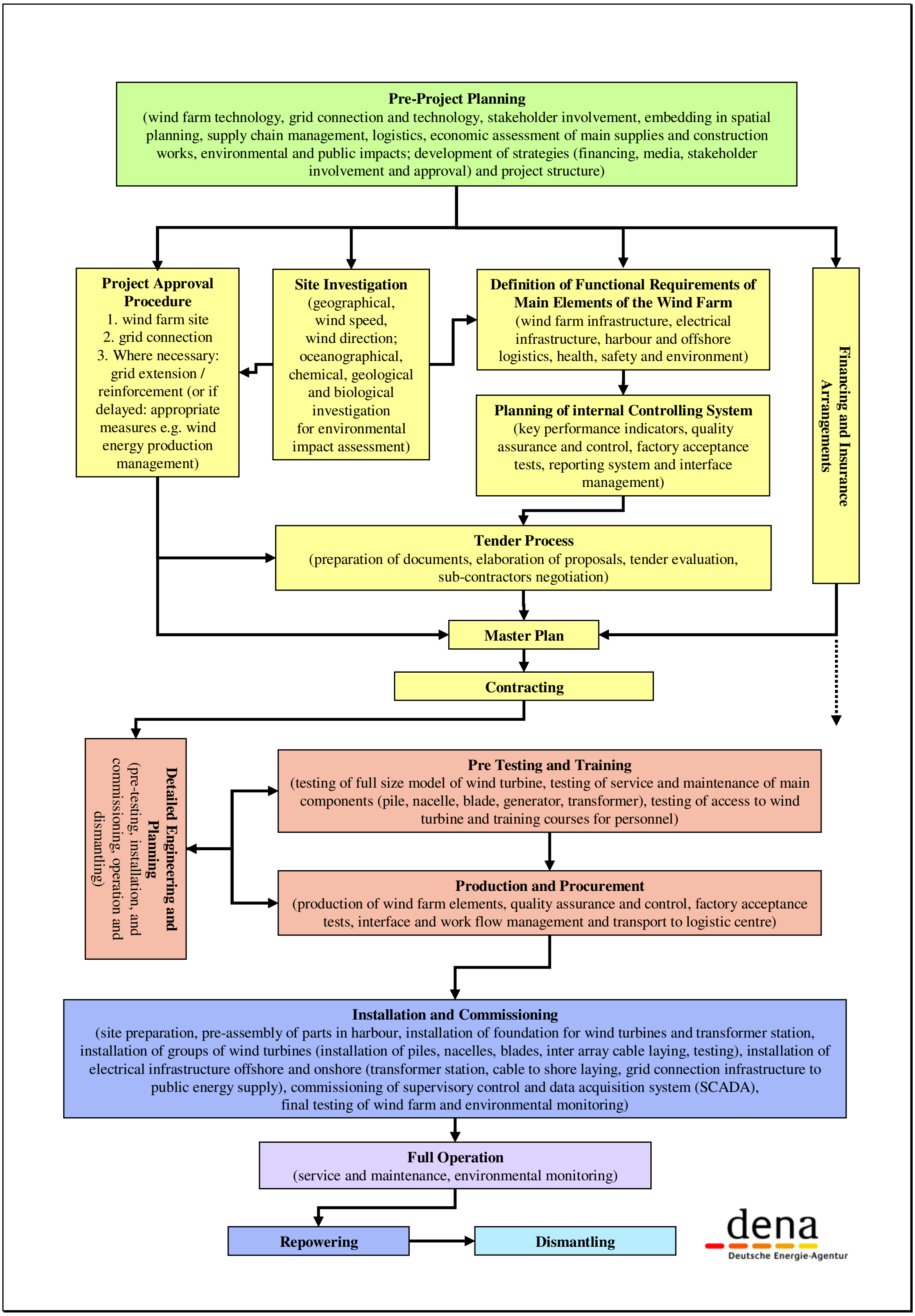

Figure 2: Flow chart of the main work packages for the phases of offshore wind farm planning and realisation.

2. Pre-planning, project planning, management and approval

Direct governmental involvement can generally be positive, as it enables sound spatial planning by identifying the most suitable areas for offshore wind farm installation and avoiding major conflict zones. National planning can in fact lead to the determination of the most appropriate areas. A screening process can contribute to minimising potential conflict.

On the other hand, it can be seen that direct governmental involvement in selecting sites for offshore wind farms can also have a disadvantageous effect if the government does not allow for a certain degree of flexibility in permit requirements, procedures etc. By selecting the wind farm site and determining the technical framework strictly, final technical optimisation has not proven possible. Sticking to previously set site conditions, which may be outdated by modern technological developments, does not permit the area available for wind farms to be optimally used, with optimal turbine spacing and technology.

The characteristics for the first projects has been an often step-by-step planning procedure, which has shifted the focus of work efforts after finalisation from one approval issue to the next. With increased experience, it can be expected that ever more of the planning and approval procedures can be done in parallel, which will speed up the planning and implementation process. Also, offshore and onshore work packages can be performed in parallel.

A major advantage in the approval phase is the existence of just *one* major approval authority, responsible for and managing the entire approval procedure. If approval is not well coordinated, several authorities may have to be addressed for different approval matters in the EEZ: The approval for the grid connection would have to be split up into offshore EEZ, offshore 12-nmi zone and onshore cable route. For the approval in the 12-nmi zone, again, different authorities would participated in the approval process. This would lead to time consuming and expensive procedures, which could better be streamlined.

Stakeholder involvement and implementation of media strategy can avoid many potential conflicts, and thus preclude opposition to projects. Stakeholder involvement should be given high priority in the pre-planning phase of a project.

From the projects realised, it can be gathered that the main obstacles in the planning and realisation of projects were a lack of experience on the part of planning authorities, or of project developers, and underestimation of the time required to plan the project, i.e., for the tender process.

Recommendations:

- The pre-selection of sites by authorities in the framework of a screening process provides major advantage for the approval process. It helps avoid conflicts, unnecessary approval procedures and site investigations. Moreover the approval process can be accelerated and a higher level of planning safety for the project developer can be reached.
- The approval should give as much flexibility to the developer to decide which technology to use, e.g which type of multi-megawatt wind turbine generators to install. This will allow the developer to benefit from a rapid engineering process.
- During the "detailed project planning" phase some work packages should be realised in parallel, because they are a prerequisite for the tendering process and the contracting: project approval procedure, the site investigation, and the definition of functional requirements of major elements of the wind farm.
- In light of the positive experiences of the Nysted Offshore Wind Farm, the project planning process should take into account the following work packages: pre-testing of a full sized wind turbine model, testing of the service and maintenance of the main components (the pile, the nacelle, the blade, the generator, and the transformer), testing of access to the wind turbine, and

training courses for the personnel. These work packages should be completed and evaluated before the production of wind farm elements starts.

- The appointment of a single leading authority for the complete approval process is of high value for both, the planning authorities and the project developers. The approval process is streamlined, avoiding a number of discrepancies and a considerable amount of organisational effort for the planning party. One of the main benefits is the single approval process for the offshore EEZ, the offshore 12-nmi zone and the onshore grid connection and cable route. A "one-stop shop" office approach is recommended.
- A governmental screening process as performed in Denmark allows the best selection of suitable offshore sites with minimum impact to the environment, nature and other concurring uses, while at the same time providing a high level of planning safety for the developing company.
- A professional media strategy is helpful for increasing public awareness of offshore wind farms in general, and also for specific projects. Media campaigns can be valuable for raising public acceptance, particularly with regard to tourism and nature impact issues.
- A media strategy can be improved for many offshore wind farm projects. Websites, information centres, newsletter and press information can contribute to creating a positive image.

3. Procurement and contracting

Either the wind farm is delivered as a turnkey object under an EPC contract, or the project developer or owner places orders separately for the main project tasks (multi-contractual approach). In the first case, the EPC is the sole contractor with the wind farm owner, and must bear all risks and warranties. It places orders with different subcontractors and tries to pass on the risks and warranties to each of them. As the offshore wind energy business still faces relatively high uncertainties for the installation process (mainly weather), the resulting cumulated risk is rather high.

In the latter case, the multi-contractual approach, the orders for the individual building segments are placed directly by the future owner. While the risks in the individual segments are basically the same as in the first case, the cumulative risks faced by the future owner may be reduced, due to the presence of overall risk management for the entire project.

Some projects simply could not cope with the preparations for such a project, and depended on external expertise and knowledge on this. For them, there was no choice other than EPC.

The complete installation procedure of an offshore wind farm requires different individual steps, from turbine manufacturing to the start of operations. The outline of this procedure is depicted in Figure 2. To reduce the costs of the construction process, the interfaces between the various projects steps, from manufacturing to commissioning, should be kept as smooth as possible. Each interface within this chain of project steps is associated with a number of expenses – for documentation hand-off, inspections, insurance, damage assessment and clarification etc.. To limit these expenses, the process from initial transportation to the installation harbour up to installation of the turbines at sea could be performed by a single company.

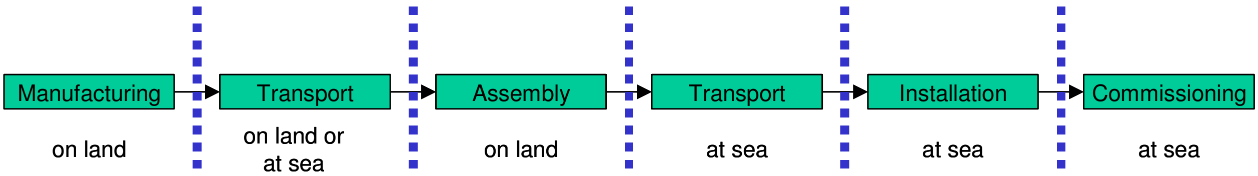

Figure-3: Single steps in the completion of offshore wind farms, from manufacturing to start of operation. An interface may be required between each step.

Recommendations:

- From the various discussions in the framework of this study, an economic advantage could be identified for multi-contractual structures for the procurement of offshore wind farms. As the provider of EPC contracts have to take on all installation risks, including all difficulties caused by bad weather, covering this risk requires a higher sales price – as much as 20% more. Therefore, the multi-contractual project concept would seem to have clear financial benefits for the developer. On the other hand, the developer must be able to control and manage the entire procurement, installation and commission process, and to deal with weather risks, as well as to share the resulting extra costs. Further evaluation and research work should be carried out in order to gain information on the important issue as to whether EPC or multi-contractual structures is preferable from an economic point of view.
- In the multi-contractual approach, the developer must have enough staff with sufficient knowledge during the planning and installation of all main elements of the project, including the reinforcement of the onshore transmission grid. The tender process requires technically highly detailed invitation and evaluation. The developer must control all interfaces between the different work packages and components, and should have full access to the contractors' design process and quality control. An excellent working relationship with the manufacturers is crucial to a successful project.

4. Installation and Grid Connection

The first projects realised in Denmark revealed the need for drastic revision of the measures of onshore and offshore logistics. While the main difficulties were seen in the offshore logistics during the project planning phase, in fact, skilled offshore companies were able to plan, prepare and perform the works in a professional manner. By contrast, the onshore logistics for transport from manufacturers to the installation harbour and assembly and loading works in the harbour itself were far more complex than expected.

In general, the realised projects show that the testing of components and complete turbines is essential. Improvements, fixes and repairs which have to be done at already installed offshore turbines are vastly more expensive (five times more than onshore) and less cost effective than if they were performed onshore (or even in the manufactory). Factory acceptance tests should be quite comprehensive, as they are invaluable to clients and contractors.

The turbine manufacturer should test prototypes of blades and turbine as well as a fully equipped, full-size model of the lower tower section, and the developer and suppliers should agree upon testing procedures during the contracting phase.

Special attention should be paid to cable-laying for grid connection. Sea cable-laying is a widely-used technology today, but more for telecommunications purposes than for energy transfer. The characteristics of power cables are very different than those of communications cables: in most cases they are far heavier, stiffer and have a larger diameter. The laying of sea cables for the offshore wind farms has proved to be time-consuming, and the necessary diver intervention was restricted by strong tidal currents. The weather window for laying the cable and commissioning should be planned long enough in advance, and should take the potential for bad weather in summer into account.

Underestimation of onshore harbour logistics is a common and serious mistake during project planning. The increase in the sizes of areas leased for the assembly of a given number of turbines shows this development for onshore requirements. While the average gross installation time per turbine was not reduced significantly, Horns Rev already had nearly the same figure as the wind farms installed later. Table 2 shows some basic data on the space needed.

For the onshore logistics, it is important to know that as long as only a limited number of turbine installations are expected for a harbour, wind farm installation is a second-priority business compared to such long-term activities as container shipping or other continuous marine business. The efforts to organise harbour logistics should not be underestimated: early planning by experienced project managers is urgently required.

Table 2: Installation of offshore wind farms (WF no. 4 is not yet built)

		1	2	3	4
Wind farm		**Horns Rev**	**Nysted**	**Scroby Sands**	**Egmond aan Zee**
Number of turbines	**[-]**	80	72	30	36
Available installation site at harbour	**[sq.m.]**	15,000	64,000	30,000	30,000
Total time frame	**[days]**	126	90	60	60
Installation time	**[days]**	105	81	55	55-90
Travel time, one way	**[hour]**	3	17	3	
Gross installation time per turbine	**[days/WTG]**	1.09	1,1	1,0	
No. of installation vessels		2	1	1	
Required installation period	**[days]**	87.2	79.2	30	

The numbers shown in Table 3 were derived from the three installed wind farms and one planned wind farm. The space typically required to assemble a turbine for offshore installation is 1000 sq.m. per WTG.

According to the experiences of installation companies, only 70 % of the days in a year are suitable for installation at sea at the listed wind farms. For wind farms, further out to sea, as most projects planned in Germany are, the time available for construction may be as low as 60 % (219 days). From the experience gained, A2SEA defined the following maximum wind speeds for installation (the main time period for installation often starts in the evening hours, when wind speeds calm down) as follows:

Installation of	**Wind speed range**
Tower and nacelle	10 – 12 m/s
Rotor blades	8 – 10 m/s

Table 3: Summary of the eight offshore wind farms investigated.

		1	2	3	4	5	6	7	8
Wind farm		**Egmond aan Zee**	**Thornton Bank**	**Borkum West**	**Butendiek**	**Greater Gabbard**	**Horns Rev**	**Nysted**	**Scroby Sands**
		Netherlands	**Belgium**	**Germany**	**Germany**	**United Kingdom**	**Denmark**	**Denmark**	**United Kingdom**
Number of turbines	**[-]**	36	6 / 24 / 60***	12 / 208	80	140	80	72	30
Turbine power	**[MW]**	3	3.6	5	3	3.6	2	2.3	2
Wind farm capacity	**[MW]**	108	21.6 /120 /300	60 / 1000	240	500	160	165.6	60
Turbine manufacturer	**[-]**	Vestas *	N.N.	N.N.	Vestas *	N.N.	Vestas	Bonus	Vestas
Expected annual production	**[GWh/a]**	345	986	260 / 4300		1750	600	480	171
Start of planning	**[-]**	2000-'02	2002	1999	2000		1998-'99	1998-'99	1993
Start of operation	**[-]**	2006*	2007*	2003* / 2010*	2008*	2009*	2003	2003	2004
Distance to land	**[km]**	10-18	27-30	45	34	23	14 - 20	9	3
Water depth	**[m]**	15-20	30	30	16-20	2.4 - 10	6 - 14	6 – 9.5	3 – 12
Investment costs	**[mil. €]**	200	100 / / 500	138	420		238	250	116
Specific investment costs	**[€/kW]**		4630/ /1667** (3472/ /1583)	2300	1750 - 2000		1488	1510	1941
Subsidies	**[mil. €]**	27	30% grid cost, max. 25	-	-	-	grid cost covered	grid cost covered	-
Feed-in rate	**[ct€/kWh]**	9.7 + actual electricity rate	10.7 + actual electricity tariff	9.1 for 14 yrs. 6.19 rest	9.1 for 12 yrs 6.19 rest		5.77 for 11 yrs		Re

* planned ** without and with subsidies *** different expansion phases

5. Economics

A general overview on the basic economic and technical figures of the investigated offshore wind farm projects is shown in Table 3. Not all figures could be made available for publication in this study, so that no general statements can be drawn from the Table. The differences in investment costs, subsidies, distance to land, water depth, subsidies for the grid connection and feed-in rates makes the economic comparison of the offshore wind farms quite difficult. The economic situation varies widely. Especially, the grid connection costs are the most impeding factor, as the distances to shore and thus the grid connection costs are very great. They can have a strong impact on the overall economic situation, and the decision of whether an offshore wind farm with high distance to land and high water depth is to be realised.

The total number of currently installed offshore wind farms is small, and very individual and specific factors influence the cost situation of these projects. Vast technological changes and new concepts for wind turbines and power transmission may be seen in future, which may have a significant influence on the costs situation as well. In addition, for some projects, the investment costs for grid connection are paid by the network operator or by the government. For some projects, direct subsidies for project monitoring are given by state authorities.

Recommendations:

- Avoiding offshore work is important for the economics of offshore wind farm projects, because the costs of work in factories compared to work at quayside and to offshore work is about 1 : 3 : 5 or more – up to 10. Offshore work can be avoided by extended testing before the serial production of wind farm elements starts: testing of training courses for personnel, testing of a full size model of a wind turbine, testing of service and maintenance of the main components (nacelle, blade, generator, gear box, transformer), and testing of access to the wind turbine. A low number of turbines must demonstrate a sufficient trial period (onshore or offshore).
- Series production should be accompanied by factory acceptance tests and quality assurance and control.
- The basic requirement for the first offshore wind farms is stable, structured financial support in situations where basic experience in operating and financing such projects is lacking. If this basic requirement is not met, the project will take much longer, and may even ultimately fail. Offshore wind energy utilisation is a young business sector which needs stable framework conditions to support its development.

6. Outlook for further activities

Further activities should concentrate on measures to reduce costs and reach higher efficiency of the whole process. In particular, the focus should be on the following aspects:

- Stable and positive conditions for offshore wind energy development
- Advantage and disadvantages of EPC contracting / multi-contracting
- Spatial planning for wind farm sites and cable routes
- Coordinated approval procedure for wind farm, cable to shore and onshore cable – if necessary: extension / reinforcement of the transmission grid
- Extended pre-testing and evaluation before serial production, quality control during production
- Good accessibility of a logistical centre, and sufficient space in the harbour / at quayside
- Avoidance of offshore work.

The full report is available for download on the POWER website at www.offshore-power.net

Contact for the POWER Case Study - Offshore Wind Farms:

For questions regarding the compilation of the document, the reader may turn to the

The Senator for Construction, Environment and Transport
Dr. Hans-Joachim Stietzel
E: Hans-Joachim.Stietzel@umwelt.bremen.de, Tel.: +49 (0)421 36117 247

or

University of Groningen:
Sjoerd Zeelenberg
E: s.zeelenberg@rug.nl, Tel: +31 (0)50 363 3885

ICBM, University of Oldenburg, as work package responsible is able to answer questions on the upcoming steps and developments of the work package:
Susanne Adam
E: adam@icbm.de, Tel: +49 (0)441 798 3623