Design of an Offshore Wind Farm in the North Sea

PROYECTO FIN DE MASTER

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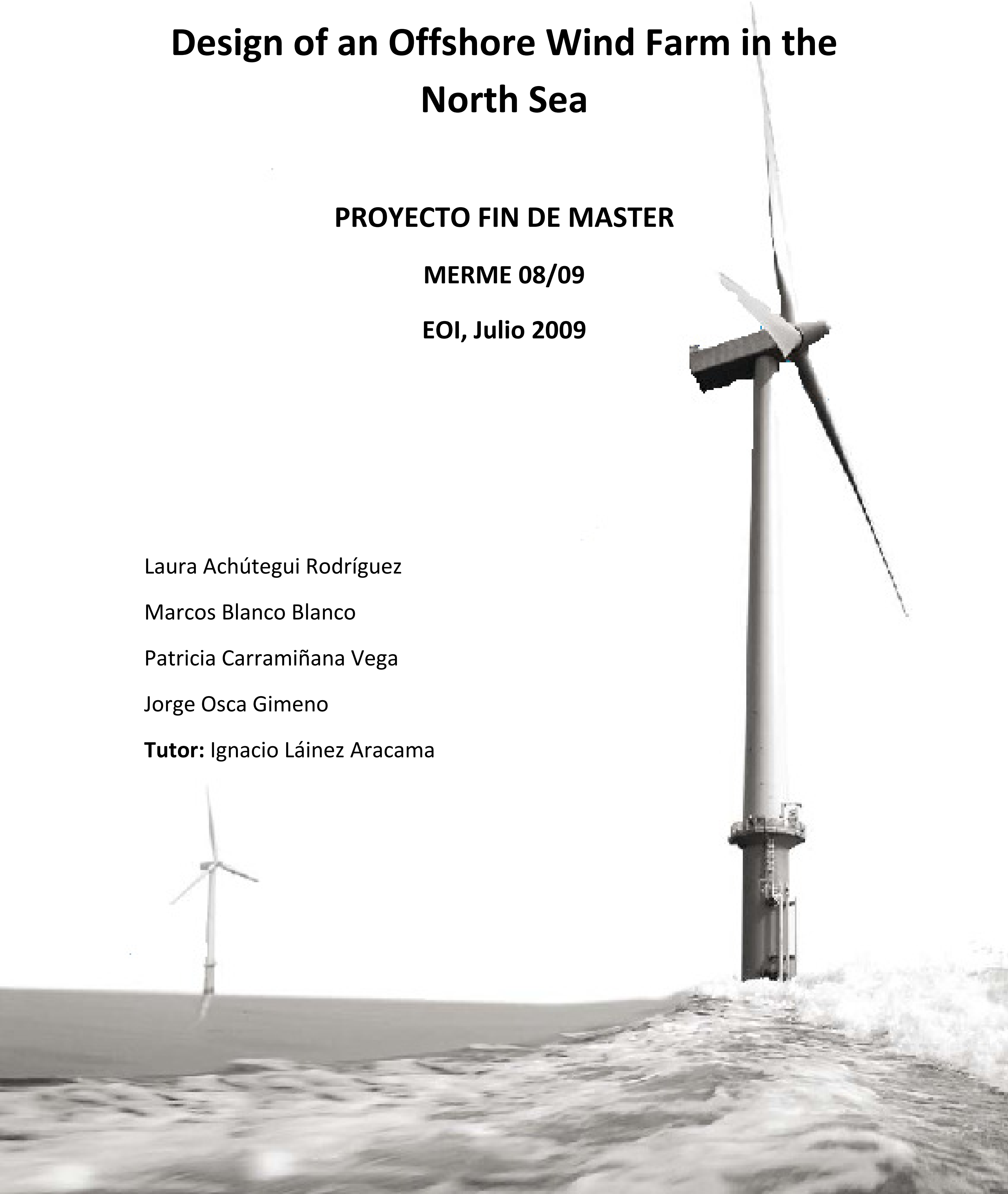
Laura Achútegui Rodríguez

Marcos Blanco Blanco

Patricia Carramiñana Vega

Jorge Osca Gimeno

Tutor: Ignacio Láinez Aracama



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EXECUTIVE SUMMARY

ABSTRACT

The EU 2020 targets imply 10 GW of offshore wind in Germany. According to calculations from the German Wind Energy Association (BWE), wind energy (onshore and offshore) could generate approximately 150 TWh/year, delivering 25% of German electricity consumption by 2020.

The main aim of the project is to design an offshore wind farm of 150 MW in the North Sea. The project is divided in one technical part, one environmental part and one economic part. The technical part of the project is divided into three work packages-Estimation of Wind Power Potential, Foundations & Installation and Electrical Collection and Transmission System-.

The environmental part includes a justification of the chosen location for the project. The wind resource has been modeled with the WASP Program. Installation process of the wind farm has been assessed from the transport phase, through installation to commissioning. A description of the installation of the foundation and the turbine has been included. Finally, the viability of the project has been estimated based on some operative and financial assumptions.

ACKNOWLEDGEMENT

Management direction for this project was provided by Ignacio Láinez, lecturer of the project. We would also like to thank to those who provided data and research: Dipl. Oz. Olaf Outzen from FINO1 Platform (BSH), Enrique Alvarez-Uría, Offshore Wind Power Expert and Alberto Sebastián, Civil Engineer.

SUMMARIES

Energy Resource Assessment

WIND DATA BASE

All the information on wind direction and velocity has been obtained from the FINO 1 Meteo Station, located in the North Sea (N 54° 0.86' E 6° 35.26', about 45 km north of Borkum).

The log contains the wind direction and velocity values of a series of 5 complete years (2004-2008) and ends with the information of January and February 2009. The selected height for the analysis is 100 m.

The accessible information contains measures of 10-minute periods of the historical series. The information is compound of average, maximum and minimum values, variance and quality factor.

Wind velocity and direction availability

During the 5 years and 2 months interlude there are 271.577 10-minute periods. Of those, up to 259.480 average velocity values are correct. This represents a 95.55% of availability.

There are 265.010 values in the provided direction series. This means an availability of 97.58 % of the total.

Wind velocity distribution in time

The monthly average velocity values are collected in the following table. As expected, the parameter arises from October to March. The windiest year was 2008 whereas the least ones were 2004 and 2006. The mean velocity of the complete period is 10.05 m/s.

(m/s)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tot.
2004	10.89	10.66	10.76	8.93	7.91	9.21	7.38	9.23	11.12	11.03	10.04	10.39	**9.76**
2005	14.61	11.25	11.40	9.67	8.83	7.93	7.66	8.62	8.68	10.50	10.71	11.49	**10.01**
2006	9.90	9.36	10.85	9.17	10.93	7.66	6.82	7.44	9.21	10.92	13.52	12.34	**9.85**
2007	15.68	11.68	11.73	9.08	8.35	7.78	9.66	8.62	11.45	7.99	12.12	10.37	**10.29**
2008	14.39	12.05	12.96	8.82	8.83	8.97	9.43	9.47	9.21	11.21	11.92	9.27	**10.35**
2009	10.68	9.82	5.00										**10.27**
Tot.	**12.41**	**10.75**	**11.52**	**9.13**	**8.97**	**8.30**	**8.16**	**8.67**	**9.89**	**10.29**	**11.66**	**10.80**	**10.05**

Table 1. Monthly and total values of mean velocity calculated from the initial data.

Wind Roses

By using the initial data, the wind roses (facing velocity bins and direction sectors) have been drawn for each month (62 wind roses) as well as for the entire series. The global wind rose is represented in Figure 1.

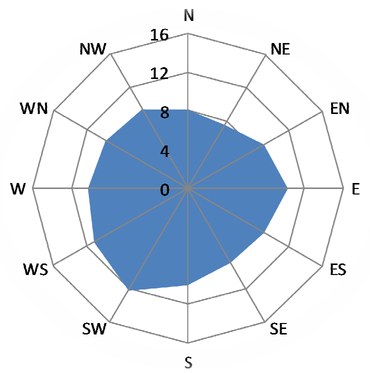


Figure 1. Initial data wind rose.

DATA MANAGEMENT PROCEDURE

The data provided by the FINO 1 Meteo Station has been managed to become representative of the location. For that purpose, the next steps have been followed.

The availability threshold

It is important to determine the values obtained from each month which do not reflect the general characteristics of that month. That implies deleting from the database those months with an insufficient availability. The threshold has been established in three fourths (75 %). This rule applies to both velocity and direction values. It has been found out that there are just five months under the threshold.

CREATING THE REPRESENTATIVE YEAR

Having a 60 month period, it is not necessary to compare with other station logs in order to assess whether we are dealing with a windy period or not.

It is important to determine the months that will compound the representative year. The mean value is the parameter used to select what are the most representative ones. The months compounding the representative year are shown in Table 2:

Jan 2004	Feb 2004	Mar 2006	Apr 2004	May 2005	Jun 2005	Jul 2005	Aug 2005	Sep 2008	Oct 2005	Nov 2008	Dec 2004
10.89	10.66	10.85	8.93	8.83	7.93	7.66	8.62	9.21	10.50	11.92	10.39

Table 2. Months of the representative year and their mean velocity values.

The year, which contributes with more months to the representative year, is 2005. The least windy year of the series is 2004, providing the representative year with only 4 months. The windiest year of the data base, 2007, does not have any component in the final year. Thus, the mean velocity has decreased until 9.7 m/s.

In conclusion this method is quite conservative. This reduces future risks of failure for the project.

LOCAL WIND FINDINGS

The figures on the main parameters, which define the local wind characteristics, are detailed below.

Frequency by Wind Direction Sectors

Table 3 shows the frequency of the different direction sectors in the representative yea. As can be observed, sectors "SW" and "WS" have a relevant importance. They correspond with the sectors between 195º and 255º.

N	NE	EN	E	ES	SE	S	SW	WS	W	WN	NW
4.59%	4.12%	5.61%	8.46%	6.62%	6.96%	8.82%	11.97%	12.85%	10.40%	11.69%	7.90%

Table 3. Frequency values of the direction sector in the representative year.

Wind rose (bins VS sectors)

Figure 2 and Table 4 represent the distribution of bin velocity values facing direction sectors. The main directions are those represented by the 210º and 240º axis. On the Figures, they correspond with West-South and South-West sectors.

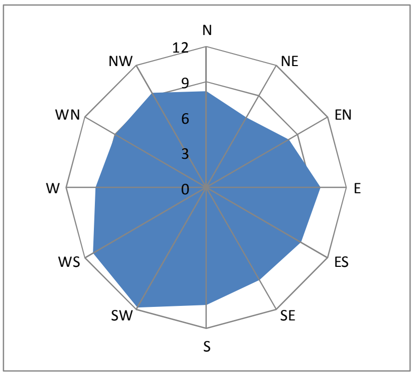


Figure 2. Wind rose of the representative year.

(m/s)	N	NE	EN	E	ES	SE	S	SW	WS	W	WN	NW	Annual
Mean Vel	8.18	6.86	8.15	9.76	9.34	9.09	10.01	11.80	11.18	9.48	8.99	9.30	9.70

Table 4. Mean velocities of the representative year, by sectors.

Power per Rotor Area

The power per swept area (the rotor area) analyzed by direction sectors is as follows:

(W/m$^{2)}$	N	NE	EN	E	ES	SE	S	SW	WS	W	WN	NW	Whole
Power	540.84	333.66	585.59	932.98	781.17	753.13	969.87	1583.59	1382.66	855.69	731.31	893.09	952.38

Table 5. Power per swept area of the representative year, distributed by direction sectors.

Energy Output

The energy output by direction sectors is compiled in the Table 6.

(MWh)	N	NE	EN	E	ES	SE	S	SW	WS	W	WN	NW	Annual
Energy	536.80	335.37	640.87	1346.69	1032.52	1019.75	1479.52	2432.46	2451.33	1570.64	1590.41	1123.55	15559.91

Table 6. Energy output of the representative year, by direction sectors.

The annual equivalent hours are calculated as follows:

$$AEH\ (h/y) = \frac{Annual\ Output\ (MWh)}{Nominal\ Power\ (MW)} = \frac{155559.91}{3.6} = 4322.2\ h$$

However, there are some loss coefficients that must be applied. These are mainly due to electric devices (transformer and grid), self consume, the wake effect, the ice deposition and the site adaptation. In total, these entire losses sum up a 15% losses factor.

WIND TURBINE SELECTION AND LAYOUT DESIGN

Commercial Turbines

Two offshore wind turbines have been defined and compared in order to select the best alternative attending to the most used one in the existing and planned projects. These are:

A) Siemens SWT 3.6-107, with a 3.6 MW nominal power, 80 m hub height and 107 m rotor diameter.

B) Vestas V90, with 3 MW nominal power, hub height of 80 m and 90 m rotor diameter.

Layout alternatives

Four alternatives have been defined.

1) 42 SWT 3.6 turbines, for a power of 151.2 MW, in a 6*7 matrix, with 8 rotor diameters separation in the parallel axis to the main wind direction sector.
2) 42 SWT 3.6 turbines, for a installed power of 151.2 MW, in a 6*7 matrix, with 8 rotor diameters separation in the perpendicular axis to the main wind direction sector.
3) 50 V90 turbines, for a installed power of 150 MW, in a 9*6 matrix (with 4 empty locations), with 8 rotor diameters separation in the parallel axis to the main wind direction sector.
4) 50 V90 turbines, for a power of 150 MW in a 9*6 matrix (with 4 empty locations), with 8 rotor diameters separation in the perpendicular axis to the main wind direction sector.

Best Alternative Selection

The final criteria used to select the best alternative, has been the calculation of the Net Annual Energy Production (AEP) by the WAsP program.The Net AEP of the four alternatives are shown below:

(MWh)	Option 1	Option 2	Option 3	Option 4
Net AEP	555874.255	553423.34	555269.603	553205.3

Table 7. Net AEP calculated for the four alternative layouts.

Therefore, the selected alternative is the *Option 1*, which is detailed in Figure 3.

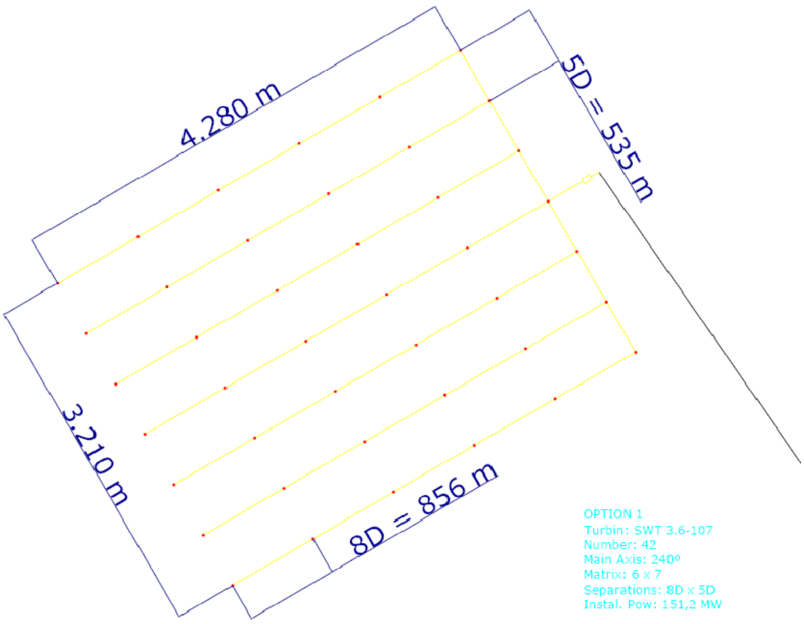
<table>
<tr><td>Installed power(MW)</td><td rowspan="20" colspan="4">
</td></tr>
<tr><td>151.2 MW</td></tr>
<tr><td>Turbine model</td></tr>
<tr><td>Siemens SWT 3.6-107</td></tr>
<tr><td>Number of Turbines</td></tr>
<tr><td>42</td></tr>
<tr><td>Number of rows</td></tr>
<tr><td>6</td></tr>
<tr><td>Row size</td></tr>
<tr><td>7</td></tr>
<tr><td>Main (Wind) Direction</td></tr>
<tr><td>240º</td></tr>
<tr><td>Main Direction Separation</td></tr>
<tr><td>8D</td></tr>
<tr><td>Separation between rows</td></tr>
<tr><td>5D</td></tr>
<tr><td>Net Annual Energy Production (MWh)</td></tr>
<tr><td>555.874,255</td></tr>
<tr><td>Annual Equivalent Hours</td></tr>
<tr><td>3676,42</td></tr>
<tr><td>4 corners UTM– X(m)</td><td>339.938,89</td><td>343.642,64</td><td>341.547,56</td><td>345.251,32</td></tr>
<tr><td>4 corners UTM– Y(m)</td><td>5.991.143,48</td><td>5.993.288,38</td><td>5.988.365,66</td><td>5.990.510,56</td></tr>
</table>

Figure 3. Main characteristics of the selected layout option.

Foundations & installation

ELECTION OF THE FOUNDATION TECHNOLOGY

Seabed Conditions

There are several parameters that condition the choice of a certain type of foundation. Most of them depend on the conditions of the site location. Therefore the initial step is to determine the seabed's composition and the water depth.

North Sea is one of the better sites worldwide to develop offshore wind energy due to its relatively low water depth in many regions because it lies on the continental shell for the most part. An analysis of the specific site of the project will be carried out in order to determine the parameters which will affect the type of foundation selection.

BATHYMETRY

Within the studied area there are three proposed zones by the German authorities considered apt to develop offshore wind energy due to their favourable bathymetry among other features. The three mentioned regions are allocated in the limit where the water depth is around 30 meters. In the south part of zone II (the one in the middle in the picture below) the water depth goes from 20 to 30 meters and there is where the wind farm will be placed.

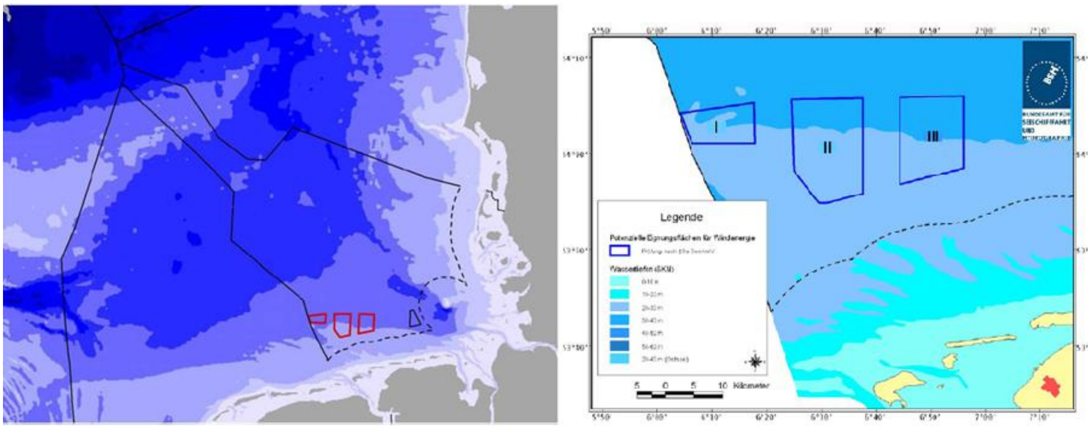


Figure 4. Overall and detailed bathymetry maps (Source: BSH)

As a conclusion of the bathymetry studies it seems fair enough to say that the foundations will be placed in a region where the water depth lies between **25 to 30 meters**.

SOIL COMPOSITION

In the selected areas the seabed is relatively flat with the exception of isolated large ripple sediment fields. In Figure 5 is represented the sediment distribution rule for the three valuable areas which consists predominantly of fine and medium sands and goes over in western direction to the Borkum sandbank becoming coarse sand. The fine grain (silt and clay) lies as a rule representing less than 5 weight per cent. From the current perspective on the seabed knowledge no stones, stone fields, boulder clays or reefs appear in the sea bottom.

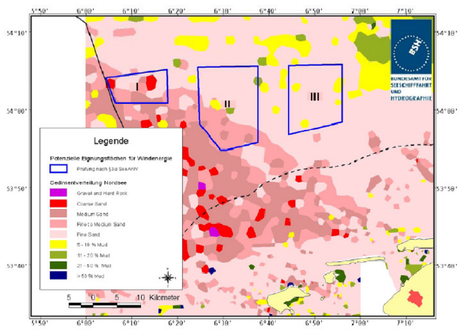


Figure 5. Sediment distribution within the studied area

Going further analyzing zone II a specific description is made. The area covers 256.5 km ². The water depths reach depths of 23 meters in the southeast and increase to the north up to 33 meters. In this zone the sea bottom shows a weakly homogeneous sediment distribution from the fine sands in the NE to the medium sands in the SW. After the results of seismic profiles the average thickness of the North Sea temporal sediment layer varies between 1.5 meters and 2.5 meters.

In the eastern area of zone II a drilling is present, which was brought down for the establishment of the research platform "FINO 1". Thereafter, the upper 32 meters of the sea bottom are built up from the ice-age fine to medium sand. Five kilometers to the east of the partial surface a research drilling up to 200 meters under the seabed proved that the first 8 meters consist of ice-age sand and under it a profile of 65 meters of loam or marls deposit lays.

Available foundation technology

Despite the wide range of foundations developed up to now, only two of them will be considered due to the fact that the remaining technologies have not been commercially tested yet and there are not cost-competitive for commercial purposes at this project's conditions, mainly water depth. These two types of foundations are gravity foundations and monopiles.

Gravity Foundations

The foundations are built onshore near the proposed site using reinforced concrete, then either floated or carried out to their designated position. They are then placed and weighted down with ballast (sand, gravel, and iron ore) to achieve their full design weight. Ice protection can be incorporated into the form of the foundation (in the conical shape of the foundation). Scaling these foundations means they become prohibitively heavy and expensive in water deeper than 10m. The main drawback to gravity bases is their size; this necessitates manufacture close to the wind farm site. It also relies on detailed logistical planning of the preparation and installation of the bases. Installation times must take into account sea bed preparation, this is essential in order to achieve a level surface and sufficient bearing capacity for the foundation. Many of these activities have to be concurrent to avoid delays; this places a big responsibility on planners to prevent conflict and possible dangers with different contractors.

Figure 6. Gravity foundations

Monopile Foundation

The monopile is the simplest of piled foundations and used with Offshore Wind Energy Converters (OWECs) acts as an extension of the tower down into the seabed.

A monopile is the most cost-effective foundation type for offshore wind energy conversion systems. Due to its simple global design, it is the preferred solution in areas with water depths up to 25 m and soil consisting of mostly sand. One advantage of piling is that there is no need for seabed preparation (except where seabed erosion is a problem) this removes to need for time consuming underwater preparation.

Piles can be steel, concrete or composite, in OWEC foundations this is dominated by steel. This is because its strength to weight ratio far outweighs concrete, reducing the scale of equipment necessary for installation.

Figure 7. Monopile foundations

CONCLUSION

Driven monopile is the type of foundation that best meets the needs of the site in terms of water depth, soil conditions to be installed and cost.

Sizing the monopile foundation.

Non-concurrence of the natural frequency of the OWEC with the excitation frequencies (1P and 3P) induced by the rotor has been defined as the reference condition to size the monopile.

Another simplification made is to assume that a flexible wind turbine can be modeled as a flagpole with top mass m_{top}. This model resembles the model of a mass-spring-damper system. The bending flexibility of the tower represents the spring stiffness; the damping is given in the form of a damping coefficient.

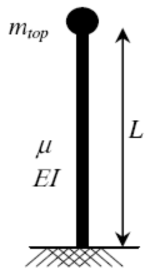


Figure 8. Structural model of a flexible wind turbine system

For this model, the natural frequency can be calculated applying the following equation:

$$f_{nat} \simeq \frac{D_{av}}{L^2}\sqrt{\frac{E}{104(a+0.227)\rho_{steel}}}$$

Depending on the approach to the stiffness of the structure (soft-soft if its natural frequency is below 1P, soft-stiffness if it is between 1P and 3P and stiff-stiff if it is over 3P value) the natural frequency value can be substituted in the equation and the average diameter can be known.

For this project, a soft-soft and a stiff-stiff approach have been analyzed to deal with an approximate reference diameter.

The results are 3.154 m for soft-soft approach (f_{nat}<0.2 Hz) and 7.414 for stiff-stiff (f_{nat}>0.8 Hz)

Since a large turbine will be used, the second one will prevail over the first one due to the decrease in 1P and 3P frequencies as the rotor diameter and hub height increase.

Installation methodology and logistics

The methodology which will be used for the pile installation is the hammer driving method. Once the type of foundation and the installation methodology are known, all the logistic aspects have to be defined in order to plan the equipments needed and the detailed schedule of operation. One of the most important points here is to determine a port which meets all the requirements needed to carry out the transportation and installation of the parts.

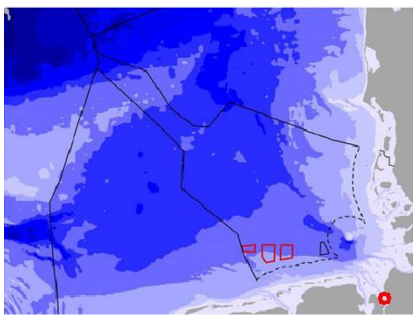


Figure 9. Bremerhaven port location

The selected harbor is Bremerhaven since this one is provided with all the necessary to store the parts as well as pre-assembly facilities and all the transportation infrastructure required.

Regarding the equipment used for the installation, a jackup barge will be the selected option to drive the monopiles. It has the limitation of about one meter significative wave height to operate. This fact leads to install the piles between April and August, when the lowest significative wave height values occur. According to the data gathered from the FINO platform, it should be around 80 days within those 5 months when the conditions are suitable to carry out those operations.

For the turbine installation over the transition piece (installed previously just after the monopile) a crane vessel will be used. The lifting operation will be carried out in three steps: one for the tower, a second one for the nacelle with a “bunny ear” (two blades) set-up and the third one to install the remaining blade vertically. Two turbines will be installed per saliling.

DECOMISSIONING

At the end of the project lifetime, if a repowering operation is not considered, the turbines and their foundations will be removed using the same type of equipment as to be installed, or that one considered more suitable when the operation would take place.

Electrical Collection, Transmission and Control System

Now that major efforts are directed to build off large offshore wind farms far away from the coast, new challenges in the electrical connections to shore have risen and need to be optimized case by case.

REQUIREMENTS RELATED TO NETWORK CONNECTION

The most recent grid codes, including the German one, require the wind farms to vary their reactive power output dependent on the grid voltage level, in order to maintain voltage stability and limit dynamic voltage variations. Wind turbines must be capable of continuous uninterrupted operation and fault-ride through support in the case of balanced faults.

EUROPEAN AND GERMAN REGULATION

The Infrastructure Planning Acceleration Act, passed by the Budesrat at the end of 2006, alters the responsibility for financing and operating connection to the grid. Grid operators are now obligated to ensure grid connection for offshore wind farms situated further than 3 nautical miles from shore and which construction begins before the end of 2015. The cost of grid connection will be carried by the network operator and can also be distributed across all transmission network operators. Therefore, as the transmission system is not a promoter’s responsibility, its design is not included in the scope of this project. Nevertheless, the alternatives for connecting offshore wind farms to the main grid will be briefly studied for academic purposes.

This German law looks for a new system approach that can reduce considerably costs due to synergetic effects. Instead of laying each cable separately to shore, cables are laid from an offshore wind park substation, which collects the power produced by all wind turbines, to an offshore node. This can be connected to several wind parks, and is also connected to the grid connection point on land via a high-voltage submarine cable. Offshore nodes can also be connected to one other, building an electrical integrated system for offshore wind farms, reducing costs and environmental impacts.

However, along the search of information for this report, no evidence has been found about the current existence or project approval of any of these submarine cables for turbines interconnection. Therefore, as it is deeply explained in the complete report, the connection of one farm has been just considered instead of considering an electrical integrated system for several offshore wind farms. Consequently High Voltage Alternative Current (HVAC), instead of High Voltage Direct Current (HVDC) is the suitable option for transmission to shore.

ELECTRICAL SYSTEM OVERVIEW

The electrical system for an offshore wind farm comprises two parts: a collection system and the transmission system. The collection system is mainly made up of the wind turbine, the low-voltage medium-voltage transformer and the submarine cables to the offshore substation that makes possible to step up the medium voltage to high voltage suitable for transmission to shore. The transmission system is the high-voltage electrical system that delivers the power from the offshore turbine to an onshore transmission line.

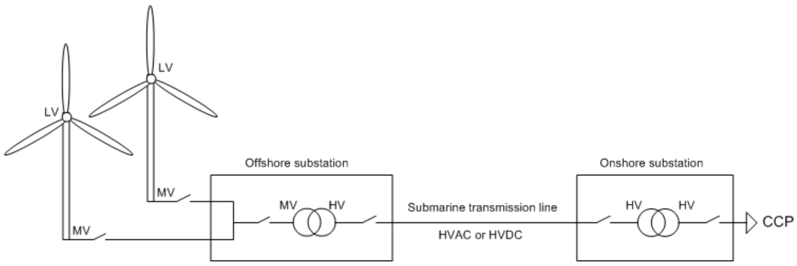


Figure 10. Electrical system scheme

Collection system

WIND TURBINE

The wind turbine that has been selected for this project is SWT-3.6-107 from Siemens, an asynchronous machine with variable speed. Asynchronous machines are robust and cost effective, but, however, do not contribute to grid voltage regulation, and they are substantial absorbers of reactive power. On the other hand, variable speed generators are more efficient and capture more wind energy by operating most of the time close to the rated power of the turbine.

Siemens wind turbines are provided with a power conversion system, named “Net Converter” which is shown in the next figure. This system allows generator operation at variable speed, frequency and voltage while supplying power at constant frequency and voltage to the medium-voltage transformer. The output of the asynchronous generator is decoupled from the grid; therefore, this system provides maximum flexibility in the turbine response to voltage and frequency requirements and fault conditions and can be adapted to meet the international grid codes.

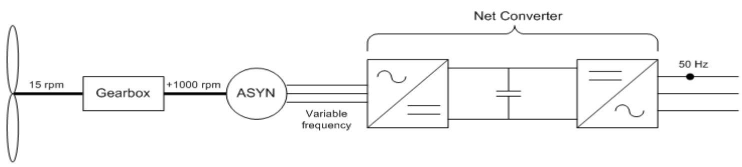


Figure 11. Siemens wind turbine scheme

LOW-VOLTAGE MEDIUM-VOLTAGE TRANSFORMER

A 4 MVA low-voltage medium-voltage transformer is used in each turbine to step up the voltage from 690 V to 30 kV in order to reduce power transmission cost, due to Ohmic resistance.

Formerly, dry-type transformers were installed for offshore applications. However, liquid-filled transformers, with fire-retardant fluid are being used nowadays because their performance and reliability, as well as their less susceptibility to corrosion, make them particularly suited for such applications, Mineral oil is replaced by silicone or ester liquid, since the latter has a higher fire and flash point as well as being more environmental friendly.

Four different locations were discussed for the transformer: inside the tower, on the access platform, at the main collection point or inside the nacelle. Finally, it has been locate inside the tower due to economic and space reasons.

MEDIUM-VOLTAGE SUBMARINE CABLE

The submarine cables connect the turbines transformers with the offshore substation transformer using 36 kV switchgears. The 42 turbines will be joined up in 7 arrays of 6 turbines each one, 6420 m the longest one and 40140 m in total.

ABB's XLPE cable has been chosen for the interconnection due to its long experience and suitability for offshore applications. As it is shown in the following table, the suitable conductor section for 6 turbines connection (30 kV, 4 MVA) is 185 mm^2.

Conductor mm²	Cable dia. mm	Mass in air, kg/m	Ratings at 33kV			Losses at full load
			Seabed temp, °C	Current, A	Power, MVA	Per phase, W/m
185	107	17	10	480	27.4	32.5
			20	449	25.7	28.4

Table 8. ABB cable specification

OFFSHORE SUBSTATION

The use of an offshore substation makes possible to step up the medium voltage to high voltage suitable for transmission to shore. The main items in the offshore substation are the 180 MVA 33/132 kV transformer and a medium-voltage and high-voltage switchgears.

A 225 kVA emergency diesel generator may be also included in order to establish an auxiliary supply of electricity to the substation as well as to the turbines. The substation will have survival rooms for technicians in case of need and rooms for equipment and refills. Each area should be carefully assessed for fire and explosion risk and protection structures may be designed accordingly.

In case of HVAC transmission system, the substation may included a system for reactive-power compensation based on SVC (Static Var Compensator technology), which will be installed at the beginning of the transmission network to provide the necessary power factor correction and improve voltage quality.

For HVDC transmission system, the AC electrical power from the offshore wind farm would be converted into HVDC at the offshore substation. Afterwards, the power would be transmitted through a submarine cable to a land based electrical network where it would be converted back again to HVAC using another substation.

In general, the size of an AC offshore substation will be only about a third of the size of the corresponding HVDC solutions, owing to the significant space required by the converter stations; so it implies a higher cost. For onshore HVDC substations, LCC technology needs considerably more space than do VSC based systems. Regarding the investements costs, DC cables and AC cables costs are similiar, but VSC converters cost is much higher than that of an HVAC infraestructure.

Alternatives to the transmission system to the grid

Two alternatives are offered for connecting offshore wind farms to the main grid: HVAC and HVDC, and two technologies can be considered for HVDC: based in a Line Commutated Converter (LCC) and in a Voltage Source Converter (VSC), which are deeply explained in the complete report.

Nowadays, the majority of existing offshore wind farms has chosen the solution HVAC in its transmission system. The main advantage is its significantly minor initial investment cost and the greater experience. However, for greater power and distances to the coast that at present, it could be not so feasible, mainly due to the production of important quantities of reactive power, offering the transmission technology HVDC more advantages, as it is reflected in the next graphic. Therefore, it is expected that for future developments of larger and further from coast offshore wind farms, HVDC technology will be widely used.

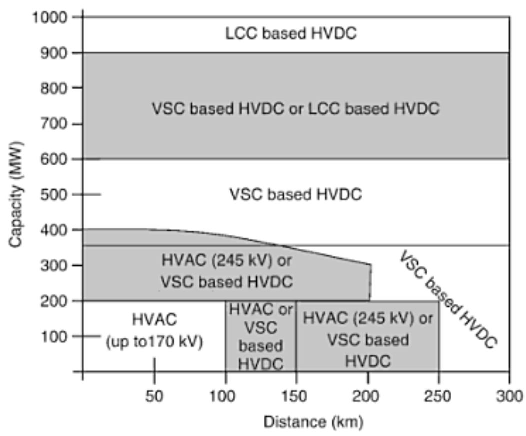


Table 9. Suitable technologies for transmission to shore

Supervisory Control and Data Acquisition System (SCADA)

The SCADA system connects the individual turbines, the substation and meteorological stations to a central computer. This system keeps records of multiple operation parameters on a very short term basis, allowing the wind farm supervision and taking any corrective action or compliance of network operator requirements when needed.

The SCADA communications network will also be used for maintenance crews' communication and broadcast quality color video is included on selected turbines to check the sea state before dispatching maintenance crews and detect unauthorized vessels fishing or anchored that may damage submarine cables.

After the comparison of three different candidate media, cooper twisted pair, radio telemetry and fibre optic; fibre optic has been chosen among the others since it is suitable for offshore applications and provides the best data rates for long distances.

The SCADA system will be provided by an independent supplier instead of by the turbine supplier, as it facilitates the coordination of different parks for owners and system operators.

Environmental Impact Study on the Offshore Wind Farm

INTRODUCTION DOCUMENT

Environmental Impact Study Identification

The project subject to an Environmental Impact Study is the construction and implementation of an Offshore Wind Farm in the North Sea, in the area "Northern Borkum”, adjacent to the FINO 1 Research Platform. The project is located within the German Exclusive Economic Zone (EEZ) and the site comprises 13.738 km^2.

Environmental Impact Study Justification

Offshore wind farms are a renewable, but not entirely conflict-free form of power generation. Not only the effects on competing maritime uses, but also the marine environment must be taken into account in the authorisation of such wind farms. For the approval of offshore wind farms in the German EEZ, the EU’s Environmental Impact Assessment (EIA) directives and, if NATURA 2000 areas are involved, the appropriate assessment according to the Habitat Directive, are legally stipulated.

Justification of the Project’s Location

The area "Northern Borkum” is suitable for the use of wind energy, due to the fact that it shows comparatively low water depths; between 23 meters in the southeast and 33 meters in the north. Besides, the area shows an ecosystem with only low occurrence in protection-needed ways of life.

In addition, the proposed area lies within sufficient distance to the recognized sea lanes essential to international navigation in this area: to the traffic division areas (VTG) German Bight Western Approach (GBWA) and Terschelling German Bight (TGB) as well as the Emsansteuerung. Figure 1 shows three different divisions of the “Northen Borkum” area. Our project is located within the partial surface II. As can be observed, the project does not lie within any Natura 2000 area.

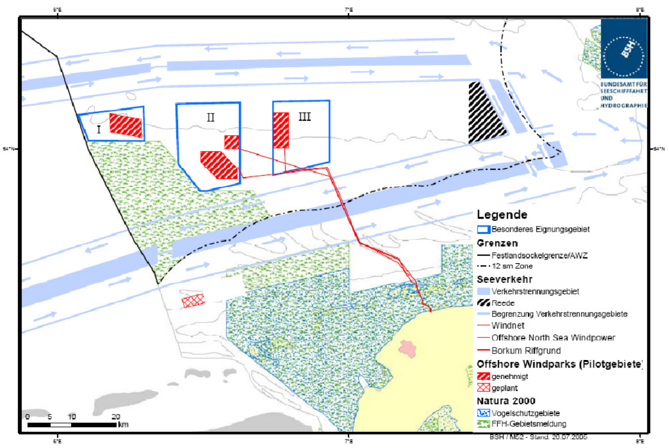


Figure 13. Subdivision and surrounding uses of "Northern Borkum" area.

Legal Framework

The main European Union Regulation, which applies to the Environmental Impact Assessment is the *Directive on the Assessment of the Effects of Certain Public and Private Projects on the Environment (85/337/EEC).*

In Germany, generating electricity by wind-powered plants is promoted by the *Renewable Energy Sources Act - EEG*. Under § 2 of the Marine Facilities Ordinance, wind farms in the Exclusive Economic Zone (EEZ)require the approval of the Federal Maritime and Hydrographic Agency (BSH). In order to get the license of an offshore wind farm in the EEZ the installations must not interfere with the use of recognised sea lanes essential to international navigation. In addition to the licensing of offshore wind farms, a permit must also be granted for laying the cable for the grid connection.

TECHNICAL DOCUMENT OF ANALYSIS OF THE PROJECT

Project Identification

- Location: **"Northern Borkum" area (North Sea)**
- Size of park: **42 turbines**
- Net Installed capacity: **150 MW**
- Production: **3500 Net Equivalent Hours (NEH)**
- Wind turbines:
  - Type: **Siemens SWT 3.6-107**
  - Height: **80 m**
  - Diametre: **107 m**
- Cable connection: **7 three-phase cables of 33kV**

Actions involved in the phases of the Project

Construction Phase	Operational Phase	Decommissioning Phase
▪ Land occupation	▪ Operation of the turbines	▪ Clearance of the area
▪ Introduction of hard substrata	▪ Presence of the wind farm	▪ Pile removing
▪ Pile driving for the foundations	▪ Waste production	▪ Waste production
▪ Cable laying	▪ Workforce requirement	
▪ Assembling of the wind turbines		
▪ Waste production		

PREOPERATIONAL ENVIRONMENT OF THE SURROUNDINGS OF THE PROJECT

Birds

Anually, more than ten million birds cross the North Sea, with considerable variation of migration intensity, time, altitude and species, depending on season and weather conditions. Potentially two particular correlations of effects exist which could constitute endangerment to bird migration:

- ✓ the danger of collision with the turbines (bird strike), and
- ✓ the barrier effect, with forced avoidance and circumnavigation of the farms by the birds, resulting in an increased consumption of energy reserves.

Habitat loss can be expected for Red-throated Diver, Northern Gannet and Common Guillemot.

Marine Mammals

Three marine mammals' species are native to the German North Sea: the harbor porpoise *(Phocoena phocoena),* the harbor seal *(Phoca vitulina)* and the grey seal *(Halichoerus grypus).*

During installation of offshore windmills, the main impacts on both seals and harbour porpoises are the noise from ramming and similar building operations, increased ship traffic to and from the construction site, installation of cables, and greater turbidity of the water. During operation of offshore wind farms the windmills emit low-frequency noise into the water, and maintenance traffic adds to this noise pollution.

Fish

The North Sea provides a habitat for approx. 250 fish species, and is among the most productive fishing waters in existence. The five species most frequently present are: the flatfishes dab (*Limanda limanda*) and plaice (*Pleuronectes platessa*), the gadoids whiting (*Merlangius merlangus*) and cod (*Gadus morhua*) and the pelagic clupeid herring (*Clupea harengus*).The main impacts, which are expected on these fish communities, are the barrier effect caused by the windmills, the damages due to the construction activities and the exclusion of fisheries activities (beneficial impact).

Benthic Associations

The conditions of life of the benthos are dependent on a number of abiotic factors, such as sediment conditions, salt content, light conditions, temperature and depth of water. Compared to natural hard substrates and coastal habitats, the species spectrum found to date on the piles shows rather low diversity. However, the present situation has not yet reached a steady "climax" state, and further arrivals are still expected.

IDENTIFICATION AND VALUATION OF ENVIRONMENTAL IMPACTS

Qualitative Valoration

The main impacts, which the construction of the offshore wind energy installation could have on the environment, are described below:

- ✓ Permanent habitat loss for sea birds
- ✓ Endangerment of bird migration due to bird strike
- ✓ Endangerment of bird migration due to the barrier effect
- ✓ Hearing damage to and/or displacement of marine mammals
- ✓ Marine pollution due to ship collisions
- ✓ Impairment of the landscape

Impact Assessment Criteria

For the valuation of impacts, a method based on the *"Leopold Matrix"* has been used, which evaluates the environmental factors that will be affected by actions during the project. The matrix of impacts identification is generated from matching the different environmental factors to the individual actions, during the construction, operation and decommissioning phase. The Complex matrix cause-effect will assign two numbers to each detected impact. The first one referring to the magnitude of the impact and the second one referring to the importance of the impact.

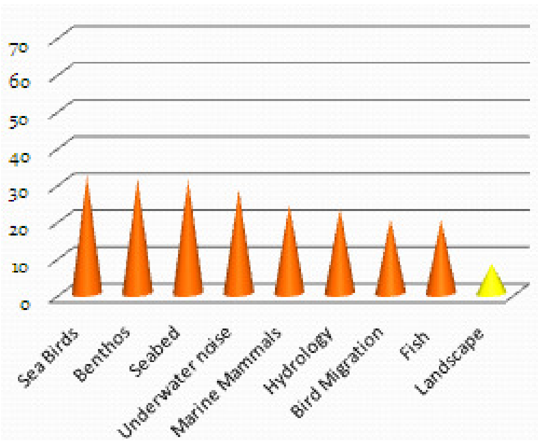
Impacts will be expressed as adverse, beneficial or negligible and the global environmental impact importance will be measured through a formula which includes extension, intensity, moment, persistence and reversibility of the impacts. Finally, the global importance of the factors will be classified as minor, moderate or major, for the beneficial impacts, and as reduced, notable and high for the adverse impacts.

Interpretation of Results

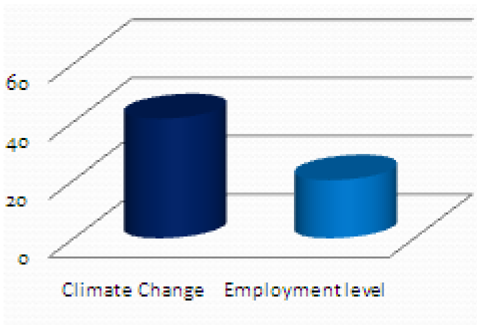
Majority of the adverse impacts will occur during the construction and operational phase. The impacts related to the construction phase are temporary and result in a moderate impact on the environment. During the operational phase some moderate impacts on the fauna has been detected. The impact resulting of the presence and operation of the wind turbines on the landscape has been considered as a minor.

On the other hand, two beneficial impacts have been found. One of them, the impact of the project on the Climate Change, has been valuated as a high impact whereas the second one, the impact of the offshore wind farm on the employment level has been considered as a notable impact.

It is therefore considered, that the proposed project will not result in either large scale or widespread environmental damage.



Graphic 1. Adverse Global Impacts



Graphic 2. Beneficial Global Impacts

DOCUMENT OF PREVENTIVE AND MITIGATION MEASURES

Mitigation measures would limit, avoid or offset the adverse environmental impacts that have been identified and where relevant, they would enhance the value of existing features. Four main mitigation measures have been proposed. These are as follows:

- *Use of internationally accepted practice* in order to comply with the Health and Safety Regulations;
- *Waste management*, following the "Recommended Guidelines for the Waste Management in the Offshore Industry";
- *Protection of birds*, by abandoning plans for wind farms in zones with dense migration and by making wind turbines generally more recognizable to birds;
- *Underwater noise reduction*, by installing large turbines.

Viability Analysis

INITIAL ASSUMPTIONS- BASE CASE

The operative, financial and valuation assumptions are listed in the tables below:

OPERATING DRIVERS	
Windfarm Region	**Northern Borkum**
Country	**Germany**
Start of Operations Date (Year)	**2010**
Success (%)	**100%**
Ownership (%)	**100%**
Net Installed Capacity (MW)	**150.0**
Capex (€ MM / MW)[1]	**2.8**
% of Investment in year 1[2]	**60%**
Hours (h)	**3500**
Feed in Tariff Years Initial Period (€/MWh)[3]	**150.0**
Initial Period (Year)	**12**
Pool+ Green Certificates Years thereafter(€/MWh)	**100.0**
Tax Rate (%)[5]	**31.5%**
Useful Life (Year)	**20**
O&M Costs in Year 1 (€ / MWh)[6]	**20.0**
O&M Warranty Period Correction Factor (%)[7]	**60%**
O&M Warranty Period (Years)	**3.0**
Days of Acc. Receivable	**60**
Days of Acc. Payable	**30**

Table 9. Operative Assumptions.

FINANCIAL DRIVERS	
Cost of Debt (Kd)[8] (%)	**7.1%**
Cost of Equity (Ke)[9] (%)	**14%**
Leverage (%)	**70%**
Loan life (years)	**15**
Tail[10] (years)	**2**
Initial Debt (€ MM)	**294.0**

Table 9. Financial Assumptions.

VALUATION DRIVERS	
Valuation Date	**21/6/2009**
WACC (%)[11]	**7.6%**
Terminal Value	**0%**
Decommissioning[12]	**5%**

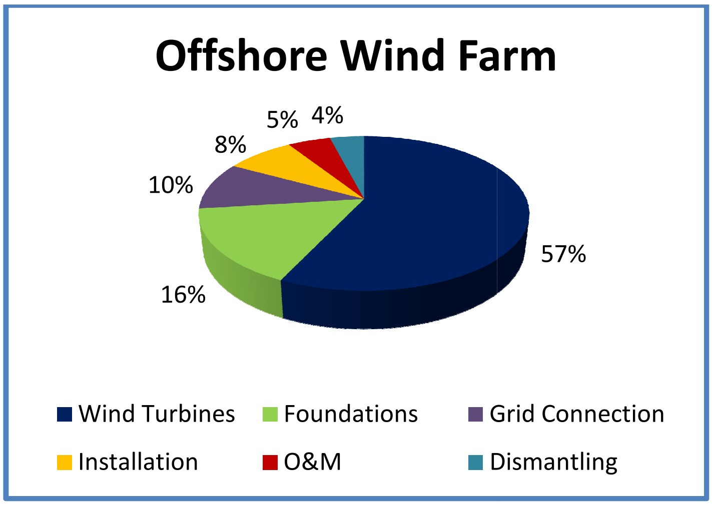
Table 10. Valuation Assumptions.

[1] Source: Carbon Trust Report.
[2] The percentage of investment for the first year has been assumed as 60% since we consider that the project will not be completely finished during the first year.
[3] In Germany, an initial tariff of 15 cents/kWh will be paid for a period of 12 years (Source: EEG).
[4] A price of 10 cents/kWh (pool price+ green certificates price) has been assumed to be paid for the remaining 8 years of the project (Source: market estimates).
[5] Source: KPMG Report.
[6] Source: Market estimates
[7] The O&M Warranty Period and the O&M Warranty Period Correction Factor refer to the fact that during the first 3 years, the maintenance costs will be the 60% of the future maintenance costs.
[8] 10Year Spanish Bond + 300 bps
[9] Source: Market estimates.
[10] A *tail* of 2 years means that we will not start paying the loan until the second year.
[11] Implied WACC from base case financing assumptions.
[12] % Initial Capex

FINANTIAL MODEL OF THE OFFSHORE WIND FARM

Investment

Graphic 3 (Sources: Lako 2002; Junginger and Faaij 2004; Junginger 2005) show the weight of the different average costs for the installation of an offshore and wind farm. This graphic highlights the relative weight of the foundations and the electricity grid connection costs of the offshore wind farms.



Graphic 3. Average costs for the installation of an offshore wind farm. Note: Grid Connection costs include substations (HVDC, Offshore AC). Onshore AC substation is to be paid by the network operator.

A ratio of **2.8 M€/MW** has been considered for the estimation of the total investment. Therefore, the Project will have an initial investment of **420,000,000.00€.** The different entries of this estimation are shown in Table 11.

CONSTRUCTION COSTS	
Wind Turbines	243,600,000 €
Foundations	67,200,000 €
Grid Connection	42,000,000 €
Installation	33,600,000 €
O&M	21,000,000 €
Dismantling	12,600,000 €
TOTAL	**420,000,000 €**

Table 10. Construction costs for the Northern Borkum Offshore Wind Farm.

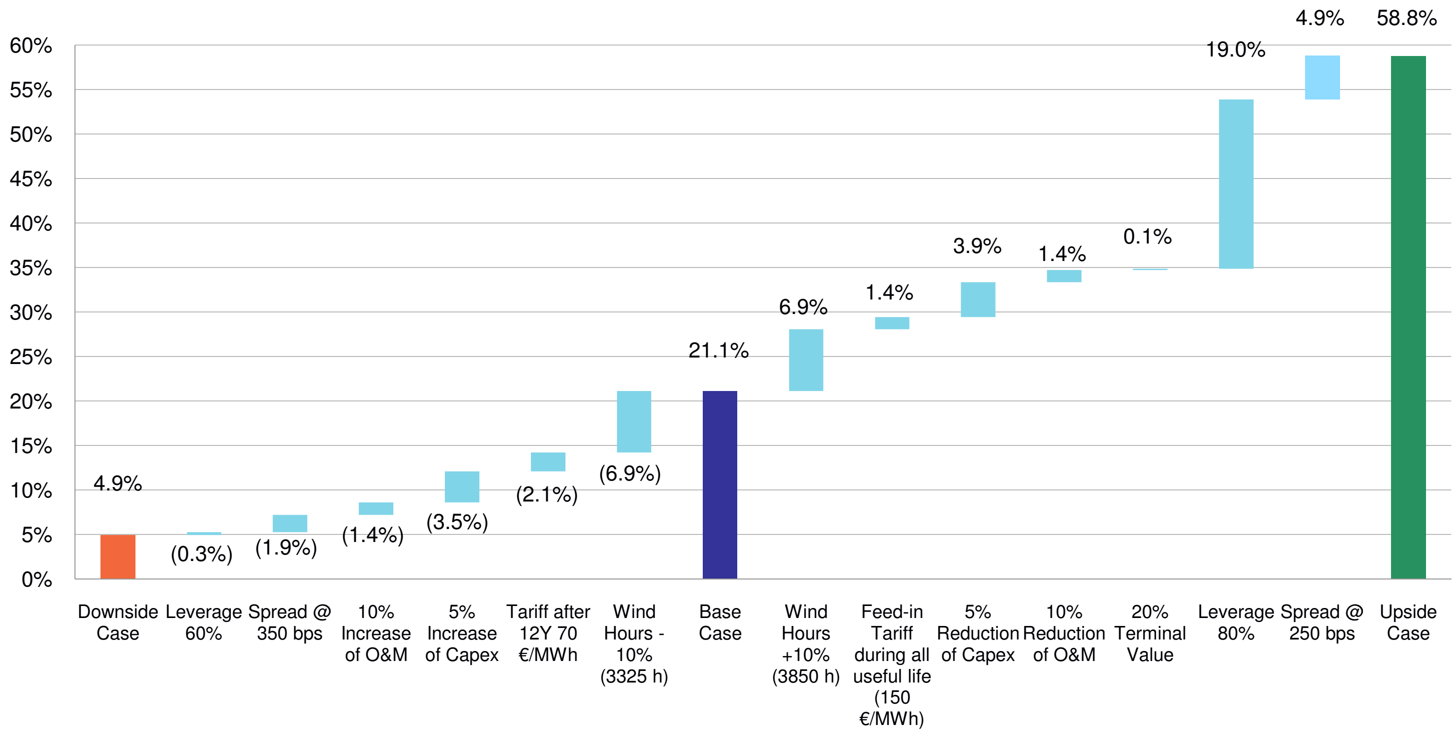
Free Cash Flows

The Free Cash Flows (FCF) has been calculated by using the DCF (Discount Cash Flow) Method, which is the most internationally accepted method for evaluating the profitability of a project.

Net Present Value

By discounting the cash flows, the net present value obtained is **76,600,000.00€.**

SENSITIVITY ANALYSIS TO SHAREHOLDERS' RETURN[13]



This sensitivity anlalysis has been made using the levered IRR in order to include the financial structure of the company as part of the analysis.

The waterfall chart shows how the initial levered IRR[14] (21.1%) is increased and decreased by a series of intermediate values, leading to a final bullish value and a final bearish value.

As can be observed the wind hours, the capex, the leverage and the cost of debt (these last two, when bullish scenarios are considered) seem to be the drivers leading to higher IRR marginal variations.

Graphic 4. Waterfall Chart- Sensitivity Analysis to Shareholders' Return.

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[13] Assuming a consecutive sequence of scenarios.
[14] Assuming a leverage of 70%.

SENSITIVITY ANALYSIS

A negative and positive deviation of (+/-) 5% and (+/-) 10% has been analyzed in order to assess the sensitivity of the results.

Sensitivity Analysis of Unlevered IRR

Unlevered IRR (%)

Capex (€ MM)	NEH (Hours) -10%	-5%	3,500	+5%	+10%
+10%	7.9%	8.7%	9.5%	10.3%	11.0%
+5%	8.6%	9.4%	10.2%	11.0%	11.9%
2.8	9.3%	10.2%	11.0%	11.9%	12.7%
-5%	10.2%	11.0%	11.9%	12.8%	13.7%
-10%	11.0%	12.0%	12.9%	13.8%	14.8%

Unlevered IRR (%)

Pool Price (€/MWh)	NEH (Hours) -10%	-5%	3,500	+5%	+10%
+10%	9.6%	10.5%	11.3%	12.2%	13.0%
+5%	9.5%	10.3%	11.2%	12.0%	12.9%
100.0	9.3%	10.2%	11.0%	11.9%	12.7%
-5%	9.2%	10.0%	10.9%	11.8%	12.6%
-10%	9.0%	9.9%	10.8%	11.6%	12.5%

Sensitivity Analysis of Levered IRR

Levered IRR (%)

Capex (€ MM)	NEH (Hours) -10%	-5%	3,500	+5%	+10%
+10%	9.3%	12.2%	15.1%	18.1%	21.1%
+5%	11.8%	14.9%	18.0%	21.1%	24.4%
2.8	14.5%	17.8%	21.1%	24.6%	28.1%
-5%	17.6%	21.1%	24.7%	28.5%	32.3%
-10%	21.1%	24.9%	28.9%	33.0%	37.2%

Levered IRR (%)

Leverage (%)	Cost of Debt (%) 6.50%	6.75%	7.10%	7.25%	7.50%
80%	37.0%	34.9%	32.0%	30.9%	28.9%
75%	28.0%	26.7%	24.9%	24.2%	23.0%
70%	23.2%	22.3%	21.1%	20.6%	19.8%
65%	20.3%	19.6%	18.8%	18.4%	17.8%
60%	18.3%	17.8%	17.1%	16.8%	16.3%

Table 11. Sensitivity Tables.

Assuming that the project is 100% equity financed and a deviation of +/-5% over the selected operating drivers would result in return from 9.4% to 12.8% for an investor.

However, assuming that the project is partially financed with debt investors would substantially increase their returns. Sensitivity analysis shows how the marginal increase of IRRs is significantly affected in bullish scenarios (this rule also applies to bearish scenarios)

CONCLUSION

- The NPV of the project is higher than zero.
- The unlevered IRR is **11%**, which is higher than the WACC (7.6%).
- The levered IRR is of **21.1%**, which is greater than the cost of equity (14%).
- The payback period is **8.5 years**.

Therefore, we can say that the project is financially viable.

CONCLUSIONS

The construction of the Northern Borkum Offshore Wind Farm in the North Sea is a project:

- ✓ Which complies with the EU and German Regulations
- ✓ Technically feasible
- ✓ Financially viable
- ✓ Which will not result in either large scale or widespread environmental damage

0. Introduction

CONTENTS

0.1. WIND POWER

Wind is air in motion. Since the earth's surface is made of various land and water formations, it absorbs the sun's radiation unevenly. Wind is produced by the uneven heating of the earth's surface by the sun.

Wind power is the conversion of wind energy into a useful form, such as electricity, using wind turbines. Wind power available in the atmosphere is much greater than current world energy consumption. The most comprehensive study to date found the potential of wind power on land and near-shore to be 72 TW, equivalent to 54,000 million tons of oil equivalent per year, or over five times the world's current energy use in all forms. Therefore, the practical limit to exploitation of wind power will be set by economic and environmental factors, since the resource available is far larger than any practical means to develop it.

At the end of 2008, worldwide nameplate capacity of wind-powered generators was 121.2 GW. Wind power produces about 1.5% of worldwide electricity use, and is growing rapidly, having doubled in the three years between 2005 and 2008. Several countries have achieved relatively high levels of wind power penetration, such as 19% of stationary electricity production in Denmark, 11% in Spain and Portugal, and 7% in Germany and the Republic of Ireland in 2008. As of May 2009, eighty countries around the world are using wind power on a commercial basis (Source: Wikipedia).

Electricity generated from wind power can be highly variable at several different timescales. Since instantaneous electrical generation and consumption must remain in balance to maintain grid stability this variability can present substantial challenges to incorporating large amounts of wind power into a grid system. Intermittency and the non-dispatchable nature of wind energy production can raise costs for regulation, incremental operating reserve, and (at high penetration levels) could require an increase in the already existing energy demand management, load shedding, or storage solutions or system interconnection with HVDC cables.

0.2. OFFSHORE WIND ENERGY

We can see already today that the number of new wind power installations onshore per year will decrease within a few years. In order to keep up the high level of wind power expansion, it will be necessary to further expand suitable on-shore sites, to replace older and smaller onshore plants by modern and efficient ones and to start developing appropriate locations offshore.

Offshore wind turbines are being used in a number of countries to harness the energy of the moving air over the oceans and convert it to electricity. Offshore winds tend to flow at higher speeds than onshore winds, thus allowing turbines to produce more electricity. Because the potential energy produced from the wind is directly proportional to the cube of the wind speed, increased wind speeds of only a few miles per hour can produce a significantly larger amount of electricity.

Many offshore areas have ideal wind conditions for wind facilities. Denmark and the United Kingdom have installed large offshore wind facilities to take advantage of consistent winds. Today, just more than 600 MW of offshore wind energy is installed worldwide, all in shallow waters (<30 meters) off the coasts of Europe. Proposed offshore wind projects through 2010 amount to more than 11,000 MW, with about 500 MW each in the United States and Canada, and the remainder in Europe and Asia.

0.3. ENVIRONMENTAL EFFECTS

The utilisation of renewable energies, such as offshore wind energy, makes a significant contribution towards environmental protection by reducing emissions of greenhouse gases. Expanding the proportion of wind energy – and of other renewable resources – hence ensures an ecological and sustainable power supply, and does therefore play a vital role in long-term protection of the Earth's ecosystem.

Compared to the environmental effects of traditional energy sources, the environmental effects of wind power are relatively minor. Wind power consumes no fuel, and emits no air pollution, unlike fossil fuel power sources. The energy consumed to manufacture and transport the materials used to build a wind power plant is equal to the new energy produced by the plant within a few months of operation. Therefore the impact made on the environment is very little when compared to what is gained. The initial carbon dioxide emission from energy used in the installation is "paid back" within about 9 months of operation for offshore wind turbines (Source: Garrett Gross, scientist from UMKC in Kansas City).

Danger to birds and bats has been a concern in some locations. However, studies show that the number of birds killed by wind turbines is negligible compared to the number that die as a result of other human activities, and especially the environmental impacts of using non-clean power sources. Bat species appear to be at risk during key movement periods. Almost nothing is known about current populations of these species and the impact on bat numbers as a result of mortality at windpower locations. However, it is known that offshore wind sites 10 km or more from shore do not interact with bat populations.

0.4. ECONOMICS AND FEASIBILITY

In 2004, wind energy cost a fifth of what it did in the 1980s, and some expected that downward trend to continue as larger multi-megawatt turbines were mass-produced. However, installed cost averaged €1,300 a kW in 2007 (Source: Continuing boom in wind energy-20 GW of new capacity in 2007) compared to €1,100 a kW in 2005. Not as many facilities can produce large modern turbines and their towers and foundations, so constraints develop in the supply of turbines resulting in higher costs. Research from a wide variety of sources in various countries shows that support for wind power is consistently 70–80% among the general public (Source: Global Wind 2005 Report).

Although the wind power industry will be impacted by the global financial crisis in 2009 and 2010, a BTM Consult five year forecast up to 2013 projects substantial growth. Over the past five years the average growth in new installations has been 27.6 percent each year. In the forecast to 2013 the expected average annual growth rate is 15.7 percent. More than 200 GW of new wind power capacity could come on line before the end of 2013. Wind power market penetration is expected to reach 3.35 percent by 2013 and 8 percent by 2018 (BTM Consult, 2009).

Since the primary cost of producing wind energy is construction and there are no fuel costs, the average cost of wind energy per unit of production depends on a few key assumptions, such as the cost of capital and years of assumed service. The marginal cost of wind energy once a plant is constructed is usually less than 1 cent per kWh. Since the cost of capital plays a large part in projected cost, risk (as perceived by investors) will affect projected costs per unit of electricity (Mukund R, 2006).

The commercial viability of wind power also depends on the pricing regime for power producers. Electricity prices are highly regulated worldwide, and in many locations may not reflect the full cost of production, let alone indirect subsidies or negative externalities. Most forms of energy production create some form of negative externality. For electric production, the most significant externality is pollution, which imposes social costs in increased health expenses, reduced agricultural productivity, and other problems. In addition, carbon dioxide, a greenhouse gas produced when fossil fuels are burned, may impose even greater costs in the form of global warming. Other significant externalities can include military expenditures to ensure access to fossil fuels, remediation of polluted sites, destruction of wild habitat, loss of scenery/tourism, etc. If the external costs are taken into account, wind energy can be competitive in more cases, as costs have generally decreased due to technology development and scale enlargement.

0.5. STRATEGY OF THE GERMAN GOVERNMENT ON THE USE OF OFFSHORE WIND ENERGY

The German government attaches great importance to the expansion of renewable energies with a view to effective climate protection, the development of a sustainable energy supply, greater independence from energy imports and the creation of new jobs. The German government’s goal, laid down in the Renewable Energy Sources Act (EEG), is to increase the share of renewable energies in the energy supply to at least 12.5 % by 2010 compared with the year 2000, and to double the share to at least 20 % by 2020. With this, Germany is making an important contribution to the EU’s goal of increasing the share of renewable energies in electricity consumption from 14 % (1997) to 22 % (2010). Furthermore, the German government has also set itself a long-term goal, within the framework of its Sustainability Strategy, to cover around half of energy consumption in Germany with renewable energies by the middle of this century.

In 2004 renewable energies already accounted for 3.6 % of primary energy and 9.3 % of electricity consumption. In order to achieve the German government’s further goals, the potential of various renewable forms of energy must be exploited in accordance with the best-va exploited to a large extent, the greatest potential for expansion up to 2020 lies in the wind energy sector, in particular in the field of offshore wind energy. There is both advanced technological development and proven experience with the technology in this field.

In recent years there has been rapid development in the wind energy sector (Figure 1). This process, in which Germany has played a key role, can be observed both nationally and internationally.

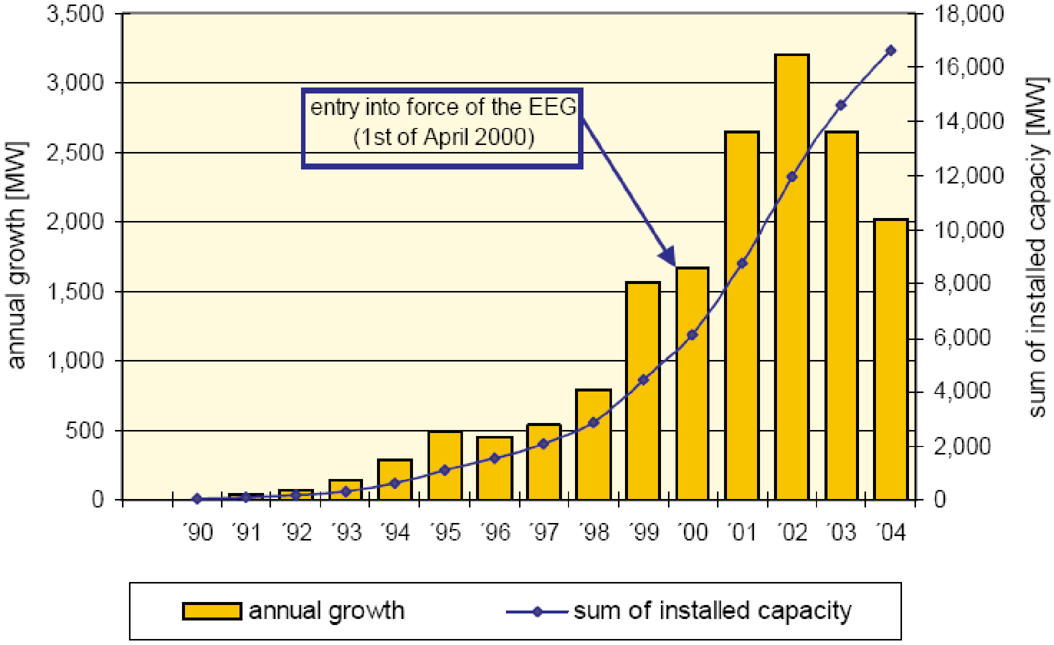


Figure 1. Expanding the use of wind energy in Germany (Source: BWE 2005, BMU 2004)

A range of successes have already been recorded. Twelve applications for offshore wind farms have already been approved (March 2006). In doing so it was possible to enforce the step-by-step principle, according to which a maximum of 80 turbines per wind farm were licensed in the first instance. Once reliable data on the impacts on maritime navigation and the marine environment are available it will be possible to grant licences for larger wind farms.

One fundamental requirement is that the expansion of offshore wind energy use is compatible with the environment and nature, and also economically viable. Prerequisites were created for the designation of protected areas and provisions for especially suitable areas for wind turbines in the Exclusive Economic Zone. Technical, environmental and nature conservation research was part of the strategy and is to accompany the expansion of offshore wind energy use for a longer period of time beyond the starting phase.

1. Energy Resource Assessment

CONTENTS

1.1. GATHERING A WIND DATA BASE. THE FINO PLATFORM

One of the reasons why the research team chose the current location for the wind farm was the availability of meteorological information. Knowing the wind velocity and direction at the location is a basic requirement for developing a consistent study.

Trough different consults to some lecturers of the current post degree, as well as searching actively in the Internet, the project team found out the viability of focus on the North Sea, in the German coast, where both the national strategy on encouraging the renewable technologies sector (specially concerning offshore wind production) and, due to this, the amount of information provided by the FINO project, seemed to make it possible.

The Federal German Government set the target of doubling the share of renewable energies used by 2010. In relation to the initial year 2000, this means a share of approximately 12.5 % of electric power generation in 2010. After 2010 this expansion is to be continued at a high level, so that by 2050, at least 50 % of the German energy supply should be based on renewable energies.

The research project FINO1[15] was initiated in 2002 with a view of determining the effects of such offshore plants on marine flora and fauna. A comprehensive series of measurements are currently being performed on a research platform in the North Sea, involving multidisciplinary investigations into meteorology, oceanography, biology, sedimentary geology and technical aspects. The results are expected to yield findings of great significance for the technical and environmental, but also the economic assessment of offshore wind technology.

Germanischer Lloyd WindEnergie GmbH (GL Wind) was entrusted with coordinating the design, construction, commissioning and operation of the platform.

In September 2003 the research platform FINO 1 started operation. At the platform, various meteorological parameters are measured, such as:

- Wind velocity
- Wind direction
- Air temperature
- Air pressure
- Air humidity
- Air density
- Rainfall
- Solar radiation
- UV irradiation
- Visibility
- Lightning flashes

For the measurement of the meteorological parameters, an anemometer mast with a height of 80

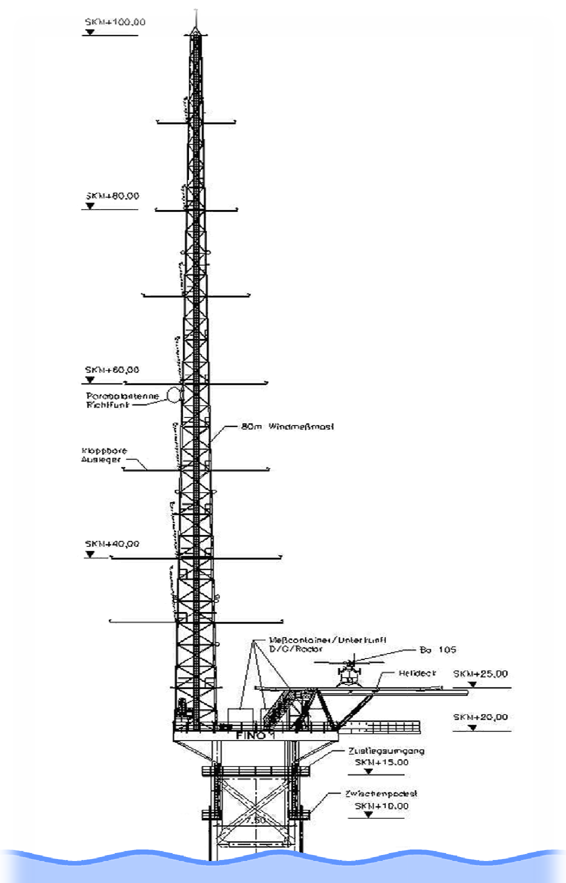


Figure 1.1 FINO 1 Research Platform

[15] *Forschungsplattformen In Nord- und Ostsee* (Research Platforms in the North Sea and Baltic)

m is installed on the platform. The maximum measurement height is 100 m over chart datum (C.D.).

The meteorological parameters are measured by means of the corresponding sensors, which are mounted at various heights on the measurement mast and at the framework of the platform. Time series are logged for most of the measurement parameters.

The results are to make an important contribution towards improving the available data for the sea region under investigation. The evaluation and application of the data is thought to make it possible to reduce the existing risks in the design, erection and operation of offshore wind turbines. In this way, manufacturers and investors have greater security with regard to aspects of plant construction and the assessment of profitability.

In addition, the meteorological measurement values obtained from the platform are being used to improve the weather forecasting.

The coordinates for the location of the measurement platform are *N 54° 0.86' E 6° 35.26'*, about 45 km north of Borkum, with a water depth of about 30 meters.

The research utilization of the measures made by the station does not have any cost, whereas its commercial use does. This being the casae, an annual fee must be paid.

The information can be downloaded from the website. Once the request has been answered, the workmen in charge provide you with a log nick and password.

1.2. DATA DESCRIPTION

The huge amount of information provided by the FINO data log needs to be categorized first and then analyzed, in order to get some conclusions on the energetic potential of the selected location.

Regarding the energetic potential, the database is composed by parameters of wind velocity and direction. These are made at different heights:

H1	H2	H3	H4	H5	H6	H7	H8
33 m	40 m	50 m	60 m	70 m	80 m	90 m	100 m

Table 1.1. Heights of the measurement devices of the FINO1 platform

The log contains the wind direction and velocity values of a series of 5 complete years (2004-2008) and ends with the information of January and February 2009.

The accessible information contains measures of 10-minute periods of the historical series. The information is compound of:

- Average value
- Minimum value
- Maximum value
- Variance
- Quality factor

1.2.1. Wind Data Availability

1.2.1.1. Wind Velocity Availability

During the 5 years and 2 months interlude there are 271.577 10-minute periods. Of those, up to 259.480 average velocity values are correct, which represents 95.55% availability. For the analysis it has been considered the average value.

The height selected for the analysis has been 100 m, since it is the most complete. However, there are some default values in the 100m series, which cannot be refilled with other data from different heights due to the fact that those same values are also default and/or missing in the rest of series.

The percentage of availability can be observed in Table 1.2.

AVAILABILITY	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tot.
2004	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.2%	99.3%	74.8%	100.0%	98.6%	97.6%
2005	82.5%	100.0%	69.7%	93.1%	100.0%	100.0%	100.0%	98.8%	100.0%	99.8%	97.5%	99.9%	95.0%
2006	100.0%	99.8%	100.0%	95.1%	100.0%	100.0%	100.0%	100.0%	99.2%	100.0%	99.6%	100.0%	99.5%
2007	93.8%	72.7%	91.6%	90.9%	100.0%	99.9%	91.6%	100.0%	85.0%	99.6%	95.5%	65.8%	90.6%
2008	43.6%	100.0%	100.0%	100.0%	100.0%	87.8%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	94.2%
2009	100.0%	100.0%	100.0%										100.0%
Tot.	86.6%	95.5%	92.3%	95.8%	100.0%	97.5%	98.3%	99.6%	96.7%	94.8%	98.5%	92.9%	95.5%

Table 1.2. Monthly percentage of availability of correct wind velocity data in the whole series

1.2.1.2. Wind Direction Availability

The direction series can be completed by combination of the measures made at different heights since wind direction is not affected by the height.

There are 265.010 values in the provided direction series. This means an availability of 97.58 % of the total. Table 1.3 details the distribution of the availability of this parameter as a total value as well as partial values by months.

AVAILABILITY	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2004	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2005	100.0%	100.0%	95.9%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.6%
2006	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2007	100.0%	100.0%	94.8%	91.0%	99.9%	100.0%	94.8%	100.0%	88.4%	100.0%	99.9%	88.4%	96.4%
2008	43.4%	89.9%	90.7%	85.7%	97.0%	91.1%	100.0%	100.0%	100.0%	100.0%	100.0%	99.8%	91.5%
2009	100.0%	100.0%	100.0%										100.0%
Partials	90.6%	98.3%	96.3%	95.3%	99.4%	98.2%	99.0%	100.0%	97.7%	100.0%	100.0%	97.6%	97.6%

Table 1.3. Monthly percentage of availability of correct wind direction data in the whole series

1.2.2. Wind Velocity Distribution in Time

The monthly average velocity values are collected in the following table. As expected, the parameter arises from October to March.

The windiest year was 2008 whereas the least ones were 2004 and 2006. The mean velocity of the complete period is 10.05 m/s. Table 1.4 shows all the monthly average velocity values.

(m/s)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tot.
2004	10.89	10.66	10.76	8.93	7.91	9.21	7.38	9.23	11.12	11.03	10.04	10.39	**9.76**
2005	14.61	11.25	11.40	9.67	8.83	7.93	7.66	8.62	8.68	10.50	10.71	11.49	**10.01**
2006	9.90	9.36	10.85	9.17	10.93	7.66	6.82	7.44	9.21	10.92	13.52	12.34	**9.85**
2007	15.68	11.68	11.73	9.08	8.35	7.78	9.66	8.62	11.45	7.99	12.12	10.37	**10.29**
2008	14.39	12.05	12.96	8.82	8.83	8.97	9.43	9.47	9.21	11.21	11.92	9.27	**10.35**
2009	10.68	9.82	5.00										**10.27**
Tot.	**12.41**	**10.75**	**11.52**	**9.13**	**8.97**	**8.30**	**8.16**	**8.67**	**9.89**	**10.29**	**11.66**	**10.80**	**10.05**

Table 1.4. Monthly and total values of mean velocity calculated from the initial data.

1.2.3. Location Specific Power

In order to compare different locations attending to the wind potential, an indicator close to the velocity is used.

From the equation of wind potential, the following expression can be deducible:

$$\frac{P}{A}\left(\frac{W}{m^2}\right) = \frac{1}{2} \cdot \rho \cdot v^3$$

Considering constant the air density (ρ) (1.225 kg/m^3), and regardless the rotor area (and therefore, regardless the selected turbine), the next table has been calculated.

(W/m^2)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tot.
2004	790.00	741.30	763.38	435.44	303.57	478.89	245.94	481.93	842.21	821.92	620.53	687.21	**569.89**
2005	1910.25	872.67	906.31	554.21	421.93	305.96	275.79	392.02	400.09	708.73	752.67	929.28	**614.29**
2006	595.13	502.64	781.64	471.93	800.53	275.76	194.25	251.87	478.52	798.47	1514.86	1149.70	**585.25**
2007	2363.01	975.42	987.57	457.94	356.30	288.17	551.44	392.01	919.41	312.04	1091.67	682.10	**667.30**
2008	1823.76	1072.34	1334.65	419.54	421.61	442.24	512.99	519.63	478.97	862.67	1036.74	488.12	**679.55**
2009	746.44	579.57	76.56										**663.62**
Tot.	**1169.66**	**760.04**	**935.31**	**466.68**	**442.39**	**349.65**	**333.22**	**399.64**	**591.88**	**668.20**	**971.71**	**772.05**	**622.12**

Table 1.5 Monthly and global power per area swept, elaborated with the FINO1 data

The Table 1.5 shows a quite energetic location, taking into account that no wind farm has overpassed the 1 kW/m^2 threshold.

1.2.4. Direction Sectors Frequency

The results of the analysis of the FINO platform data on the frequency of the wind directions are compiled in the Table 1.6.

The least frequent directions are regions between 0 and 60º (N and NE) and between 120 and 180º (ES and SE), whereas the most frequent wind direction corresponds with the region between 210 and 330º (the sectors SW, WS, W and WN).

% Dir	2004	2005	2006	2007	2008	2009	Ave
NE	4.38%	4.87%	3.65%	5.91%	3.13%	2.21%	**4.31%**
EN	4.64%	6.24%	6.25%	8.80%	6.94%	3.57%	**6.44%**
E	7.15%	7.68%	8.75%	14.90%	11.47%	6.13%	**9.78%**
ES	5.95%	5.66%	6.03%	6.18%	4.43%	9.23%	**5.77%**
SE	5.82%	7.07%	6.91%	4.72%	3.30%	9.25%	**5.72%**
S	7.51%	8.00%	9.58%	4.64%	7.98%	8.92%	**7.63%**
SW	12.98%	12.69%	15.57%	9.80%	14.77%	13.76%	**13.22%**
WS	14.63%	12.82%	11.08%	11.80%	16.10%	12.43%	**13.24%**
W	12.45%	10.43%	9.98%	10.37%	13.45%	12.03%	**11.35%**
WN	11.49%	11.74%	9.46%	9.47%	8.75%	10.51%	**10.21%**
NW	8.74%	8.27%	8.44%	8.67%	6.34%	6.70%	**8.06%**
N	4.26%	4.52%	4.30%	4.75%	3.34%	5.27%	**4.27%**
Tot.	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

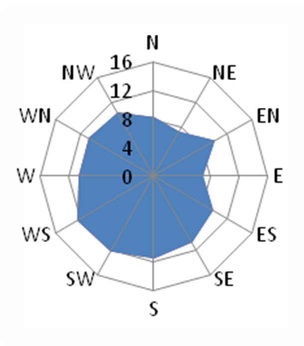
Table 1.6. Frequency of wind directions, year by year and as an average

1.2.5. Wind Roses

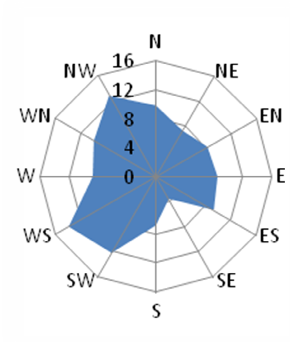
The wind roses, correspondent to the 60 months of the data series, are shown in the figures below. They represent the wind velocity values facing the wind direction sectors.

1.2.5.1. 2004 Wind Roses

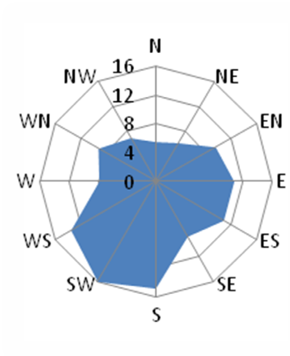
Jan 04



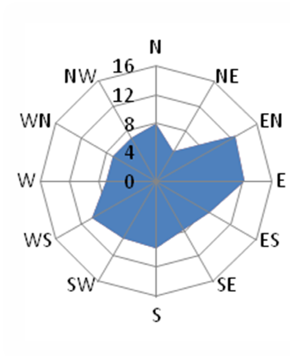
Feb 04



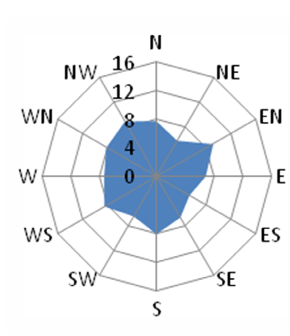
Mar 04



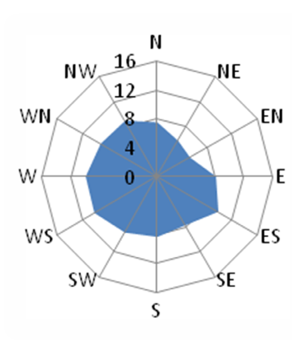
Apr 04



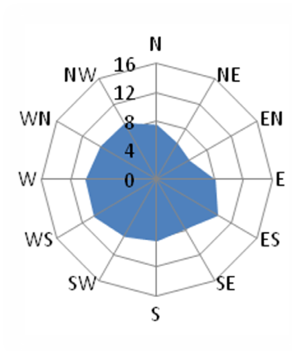
May 04



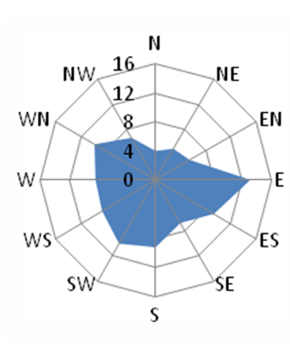
Jun 04



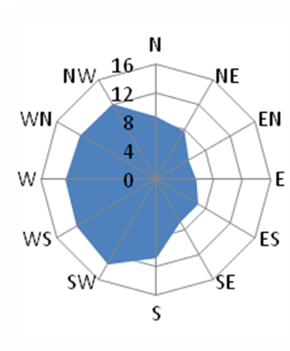
Jul 04



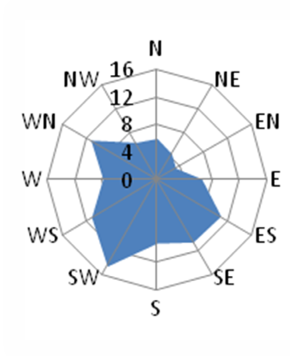
Aug 04



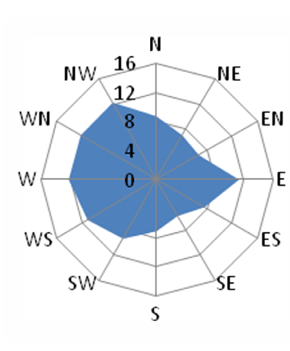
Sep 04



Oct 04



Nov 04



Dec 04

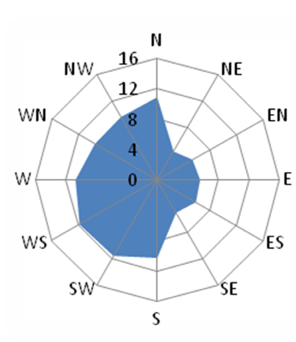


Figure 1.2. Monthly wind roses from 2004 January to December

1.2.5.2. 2005 Wind Roses

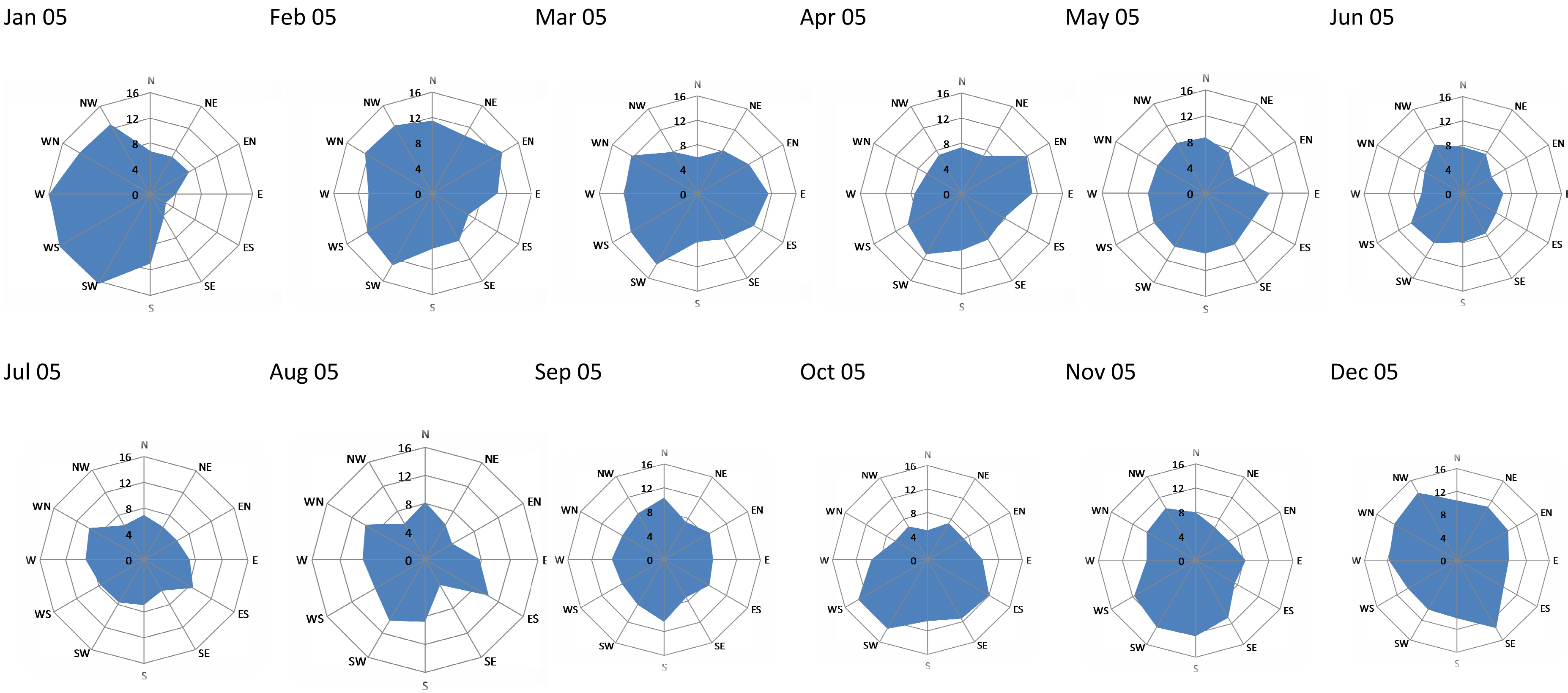


Figure 1.3. Monthly wind roses from 2005 January to December

1.2.5.3. 2006 Wind Roses

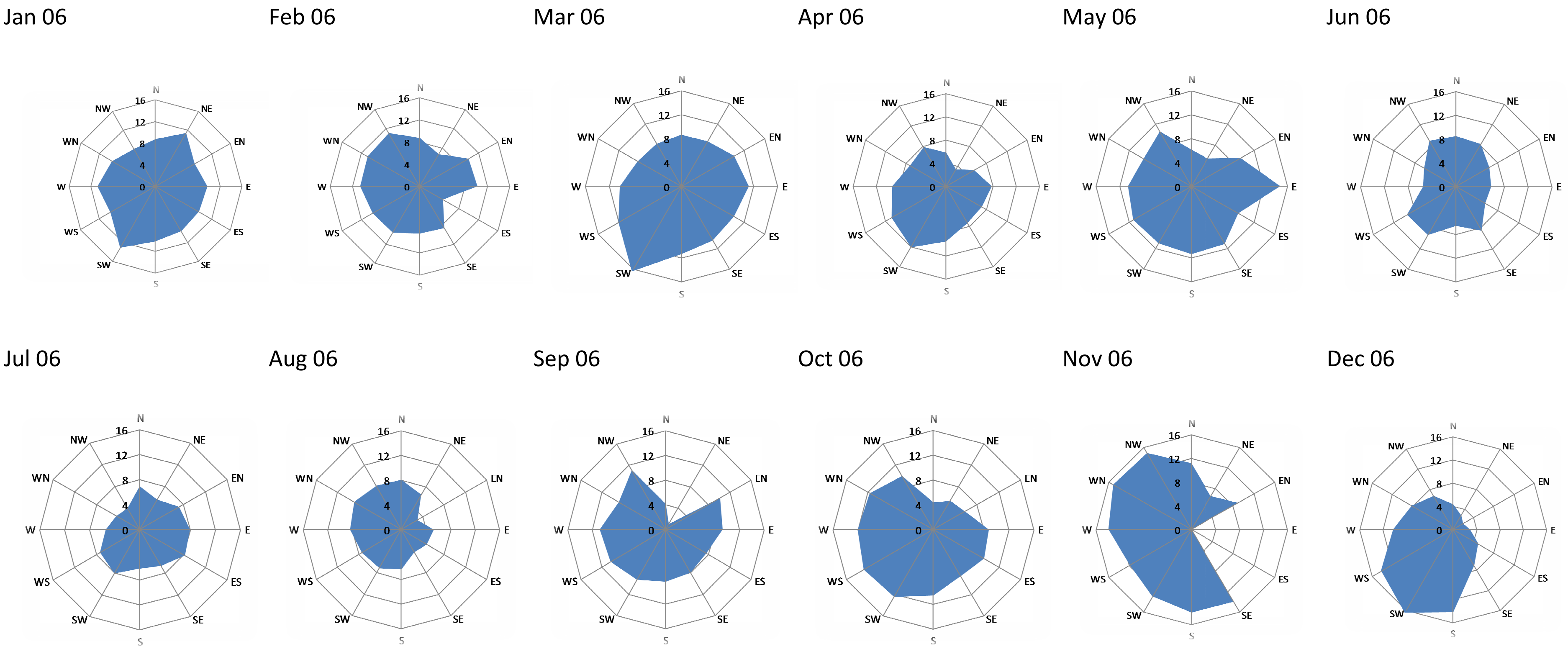


Figure 1.4. Monthly wind roses from 2006 January to December

1.2.5.4. 2007 Wind Roses

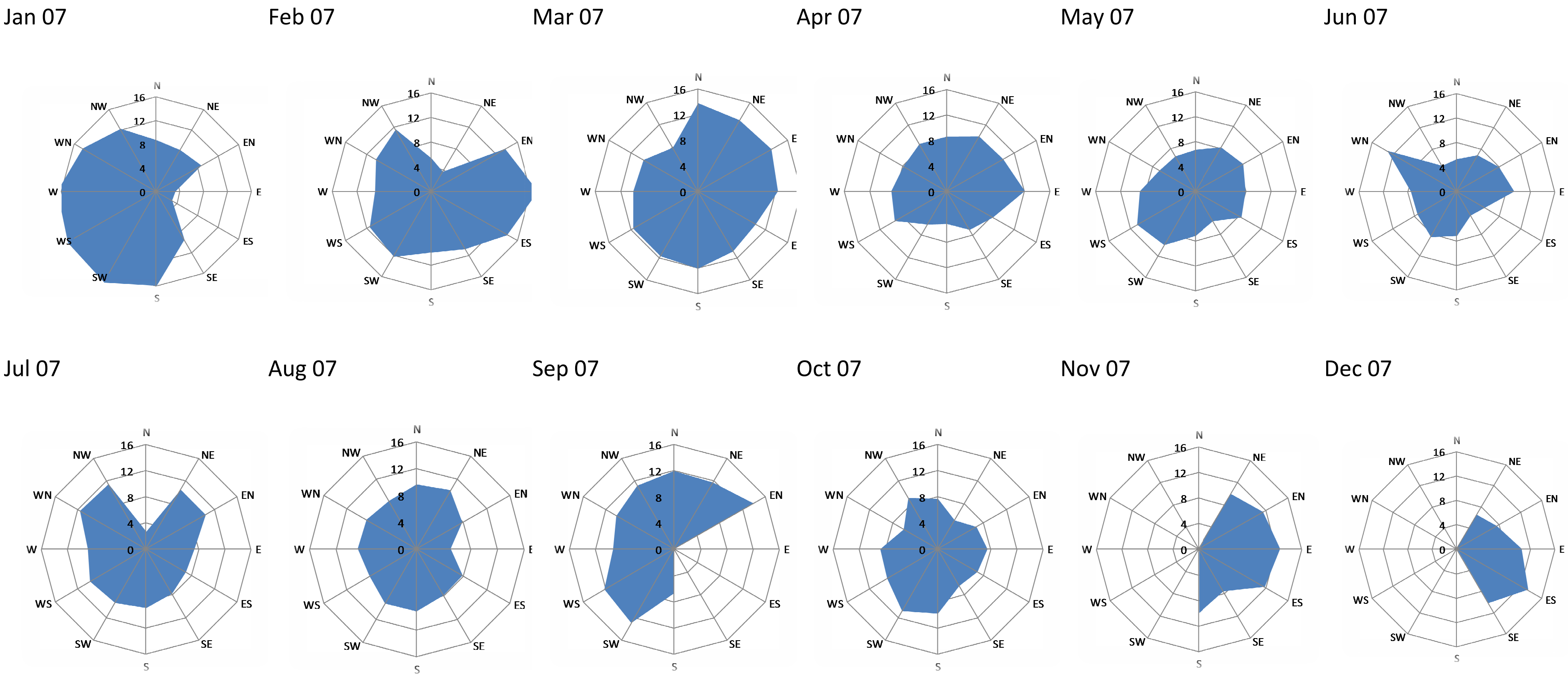


Figure 1.5. Monthly wind roses from 2007 January to December

1.2.5.5. 2008 Wind Roses

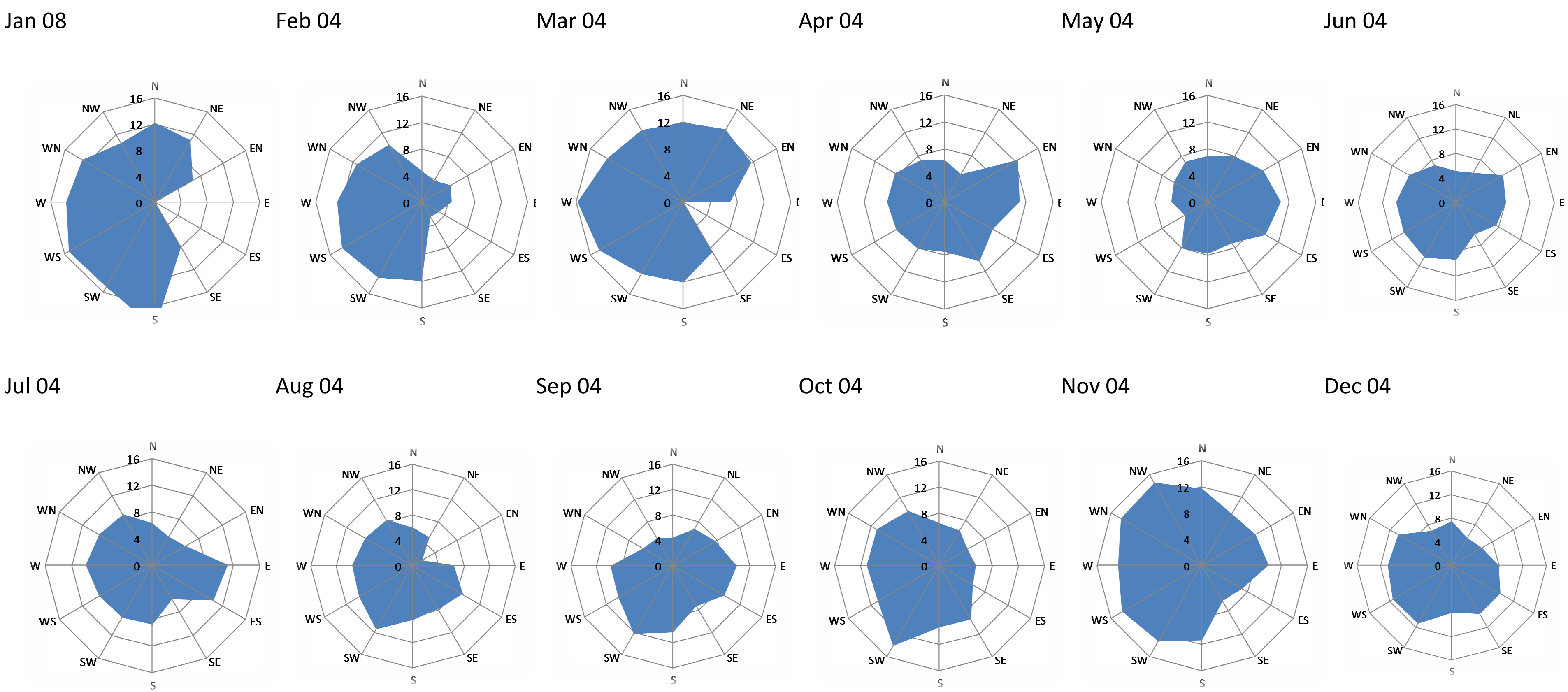


Figure 1.6. Monthly wind roses from 2008 January to December

1.2.5.6. 2009 Wind Roses

Jan 09 Feb 09

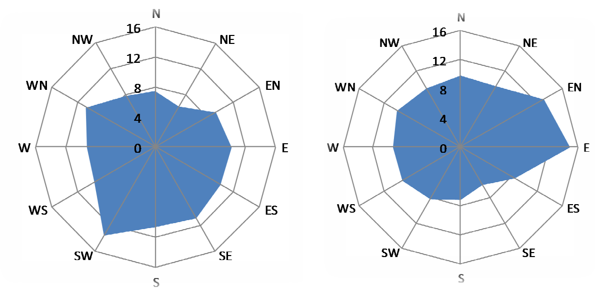


Figure 1.7. Wind roses of January and February 2009

1.2.5.7. Whole Series Wind Rose

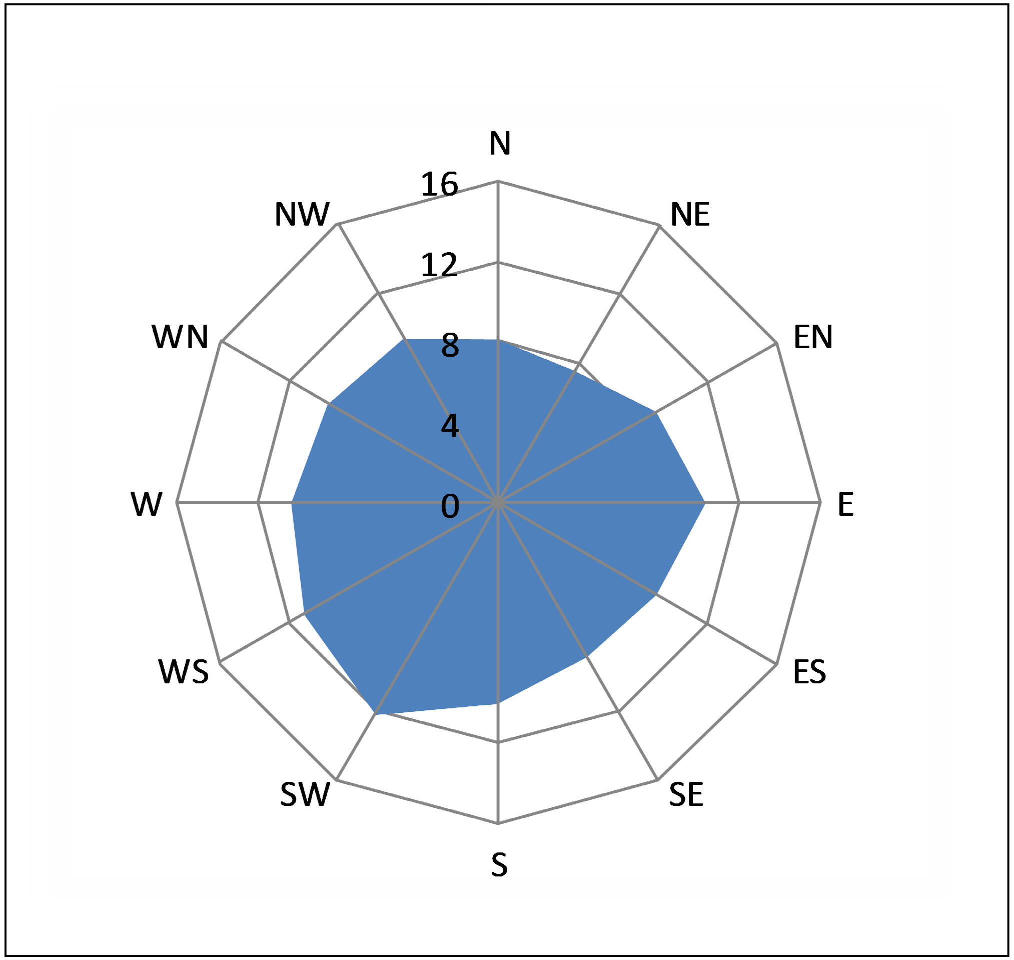


Figure 1.8. Wind rose of the total series

1.3. DATA MANAGEMENT PROCEDURE

The data provided by the FINO Meteo Station needs to be managed in order to become representative of the location.

1.3.1. The availability threshold

It is important to determine the values obtained from each month which do not reflect the general characteristics of that month. That implies deleting from the database those months with an insufficient availability. The threshold has been set up in three fourths. Therefore the monthly periods with an amount of information minor than 75 % has to be deleted. This rule applies to both velocity and direction values.

It has been found out that there are just five months under the threshold. These are 2004 October, 2005 March, 2007 February and December and 2008 January. These months have been deleted from the analysis.

1.3.2. Creating the Representative Year

It is not usual in this kind of analysis to have more than one year information. Many times we cannot even find even 6 months. In those cases it is compulsory, in order to get a trustworthy result, to find out if the observed year is windy or not, and then coherently weight down or up (as proceed) the results. In this project, the covered period is long enough to let us obviate this part of the analysis.

It is also important to determine the months that will compound the representative year. It has to be constituted by the most representative January among the Januarys observed, the most representative February among observed, etc. The velocity mean value is the parameter chosen to select what months are the most representative. That means, for instance, the selected June will be that June whose mean velocity value is closer to the overall velocity mean in June.

Table 1.7 contents the partial and total mean velocity values of the series.

VEL Monthly Ave (m/	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tot.
2004	**10.89**	**10.66**	10.76	**8.93**	7.91	9.21	7.38	9.23	11.12		10.04	**10.39**	9.67
2005	14.61	11.25		9.67	**8.83**	**7.93**	**7.66**	**8.62**	8.68	**10.50**	10.71	11.49	9.92
2006	9.90	9.36	**10.85**	9.17	10.93	7.66	6.82	7.44	9.21	10.92	13.52	12.34	9.85
2007	15.68		11.73	9.08	8.35	7.78	9.66	8.62	11.45	7.99	12.12		10.19
2008		12.05	12.96	8.82	8.83	8.97	9.43	9.47	**9.21**	11.21	**11.92**	9.27	10.18
2009	10.68	9.82	5.00										10.27
Tot.	**12.23**	**10.61**	**11.54**	**9.13**	**8.97**	**8.30**	**8.16**	**8.67**	**9.89**	**10.16**	**11.66**	**10.87**	**9.96**

Table 1.7. Monthly mean values of velocity of the current data series

Not having into consideration if the closest value in each case is higher or lower, the resulting representative year, with each month mean velocity (in meters per second), would be as follows.

Jan 2004	Feb 2004	Mar 2006	Apr 2004	May 2005	Jun 2005	Jul 2005	Aug 2005	Sep 2008	Oct 2005	Nov 2008	Dec 2004
10.89	**10.66**	**10.85**	**8.93**	**8.83**	**7.93**	**7.66**	**8.62**	**9.21**	**10.50**	**11.92**	**10.39**

Table 1.8. Months of the representative year, with their mean velocity value.

The year with more months in the representative year is 2005, whereas 2004 is the least windy year of the series, and contributes to the representative year with 4 months. However, the windiest year of the data base, 2007, does not have any component in the final year. Thus, the mean velocity has decreased up to 9.7 m/s.

In conclusion we can say that this method is quite conservative, avoiding in this way, future risks of failure of the project.

1.4 LOCAL WIND FINDINGS

Once calculated a representative year, it is possible to find out some conclusions on the frequency of the direction sectors, the representative wind rose, and the energy output, segmented by wind directions.

1.4.1. Frequency by Wind Direction Sectors

The Figure 1.9 represents the frequency distribution of the wind direction sectors in the representative year.

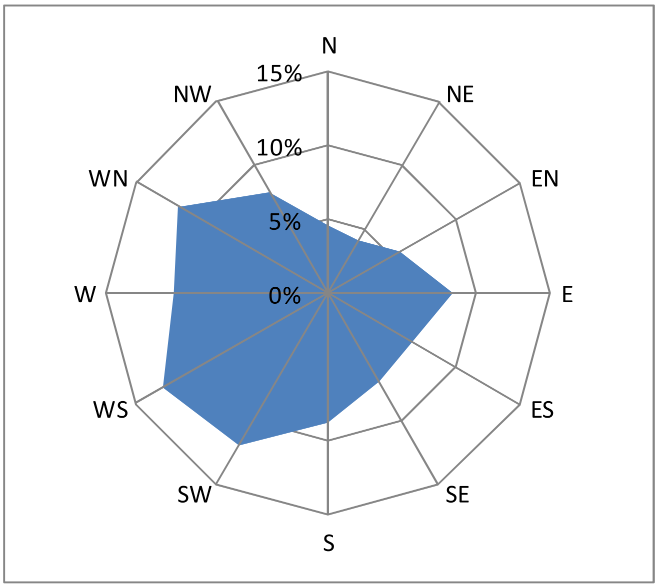


Figure 1.9. Wind rose of the wind direction sectors frequency in the representative year

The main directions correspond to sectors WS, SW and WN. In the opposite side, sectors N, NE and EN have the least frequencies in the series.

These values are contained in the Table 1.9.

N	NE	EN	E	ES	SE	S	SW	WS	W	WN	NW
4.59%	4.12%	5.61%	8.46%	6.62%	6.96%	8.82%	11.97%	12.85%	10.40%	11.69%	7.90%

Table 1.9. Frequency value of the direction sector in the representative year.

1.4.2. Wind rose (bins VS sectors)

The following graphic, commonly known as “wind rose”, represents the distribution of the mean velocities, by direction sectors, in the representative year.

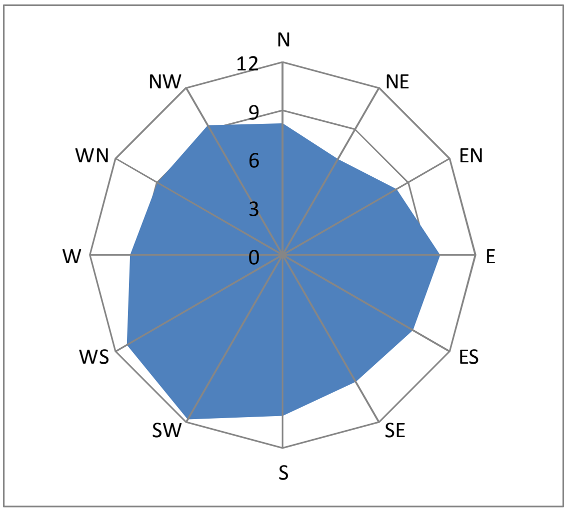


Figure 1.9. Wind rose of the representative year.

It clearly states the predominant directions of the wind in the location, which are the sector between the South and the West. The main sectors are the WS and de SW ones. The mean velocity values used to make the graphic are listed below.

(m/s)	N	NE	EN	E	ES	SE	S	SW	WS	W	WN	NW	Annual
Mean Vel	**8.18**	**6.86**	**8.15**	**9.76**	**9.34**	**9.09**	**10.01**	**11.80**	**11.18**	**9.48**	**8.99**	**9.30**	**9.70**

Table 1.10. Mean velocities of the representative year, by sectors.

As shown, the average velocity for the whole period arises to 9.7 (m/s).

1.4.3. Power per Rotor Area

The following Figure is made taking into account the unity of surface swept by the rotor and the representative year.

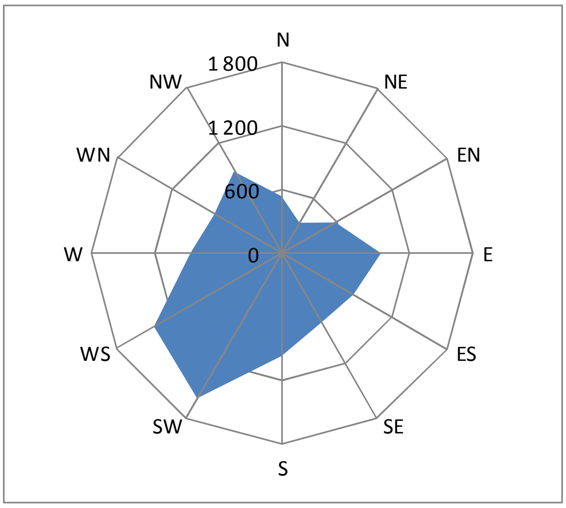


Figure 1.10. Wind rose of power per area swept, by sectors, in the representative year.

Once more, the most important directions are those between the South and the West, while the opposite sectors have the lower power per unit of surface.

The values to create the graphic are shown in the Table 1.11.

(W/m^2)	N	NE	EN	E	ES	SE	S	SW	WS	W	WN	NW	Whole
Power	540.84	333.66	585.59	932.98	781.17	753.13	969.87	1583.59	1382.66	855.69	731.31	893.09	952.38

Table 1.11. Power per swept area of the representative year, by direction sectors.

1.4.4. Energy output

With a turbine power curve and the information on the wind velocity and direction during a representative year, you obtain the rose of annual energy production by the selected turbine within one location.

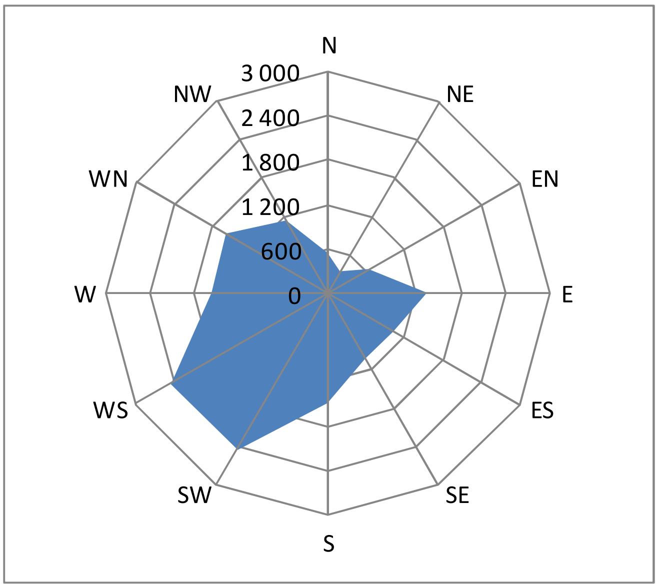


Figure 1.11. Annual energy output, by direction sector, in a representative year.

The selected turbine is the Siemens Wind Turbine rated in 3.6 MW, which is designed for both onshore and offshore wind production.

The energy units in the graphic are kWh, and the values are listed in the Table 1.12.

(MWh)	N	NE	EN	E	ES	SE	S	SW	WS	W	WN	NW	Annual
Energy	536.80	335.37	640.87	1346.69	1032.52	1019.75	1479.52	2432.46	2451.33	1570.64	1590.41	1123.55	15559.91

Table 1.12. Energy output of the representative year, by direction sectors.

1.4.5. Annual Equivalent Hours

Since the final production from the wind analysis gives an output value of 155.559,91 MWh/ year, it is quite intuitive the value of annual equivalent hours of the location.

$$AEH\ (h/y) = \frac{Annual\ Output\ (MWh)}{Nominal\ Power\ (MW)} = \frac{155559.91}{3.6} = 4322.2\ h$$

This is the first full load hours number obtained from the database, but not the final. Some lossess must be considered due to the following concepts:

- *Electric losses*. Which include grid losses (transport and transformation) and self consume. Its value varies between 3 and 4 %.

- *Availability losses*. The availability of a wind turbine is defined as the time the wind turbine is in operation or ready for operation with external conditional, for instance too low wind or grid loss, preventing the system from energy generation. The technical availability of the turbine is 97% or higher. This figure is based on data of modern operational wind farms. The other importance factor for this figure is the maintenance. It is important in this subject the paradigm of the highest production rates in winter linked to the worst accessibility to the wind farm.

- *Wake effect losses*. The wind speed downstream the rotor, the so-called wake, of the turbine is lower compared to the undisturbed wind speed resulting in a somewhat reduced performance of downstream sited wind turbines. The wake is characterized by extra turbulence which may lead to premature damage of main structural components. It is common practice to estimate the wind farm wake losses in the range of 3 to 4% of the gross energy yield. In this project it will be determined by the result given by the WAsP calculations.

- *Ice deposition and other climatologic constraints*. An average figure of a 2% is commonly accepted.

- *Site adaptation losses*. Each turbine has a power curve empirically obtained in a controlled framework. The response of a turbine in the windfarm location uses to be around a 3 to 5 % lower than in laboratory.

So, the compound losses factor to apply would be:

$$CLF = 0.97 * 0.97 * 0.96 * 0.98 * 0.96 = 0.85$$

Applied to the full load hours number obtained, the estimated annual equivalent hours parameter would arise to a figure of around *3.672,8 hours*. But this is a first estimation. Later analysis (WAsP Program) will give us a more accurate number.

1.5 WIND TURBINE SELECTION AND LAYOUT DESIGN

Optimizing the layout of an offshore wind farm presents a significant engineering challenge. Most of the optimization literature to date has focused on land-based wind farms, rather than on offshore farms. The conventional method used to lay out a wind farm combines a turbine cost model and a wake model in conjunction with an optimization routine. In offshore environments, however, factors such as operation and maintenance (O&M) and availability also play significant roles in the design of a wind farm.

In this project, the costs are not the criteria at the beginning, but will be conveniently studied in the economic feasibility epigraph.

Some alternatives are defined, combining different layouts and turbines. Then, attending to production and environmental criteria, one will be chosen. Of course, it is possible talking about optimal solution, better than good or bad solution, and that is what the team has reached through this methodology. The output results, obtained by using the WAsP tool, have been decisive in the chosen alternative selection.

1.5.1. Commercial turbines

Gathering information on the biggest offshore wind farms currently in operation, there are several manufacturers well know by the professionals. The following Table shows the most important offshore projects till the moment and some of the biggest projected for the close future.

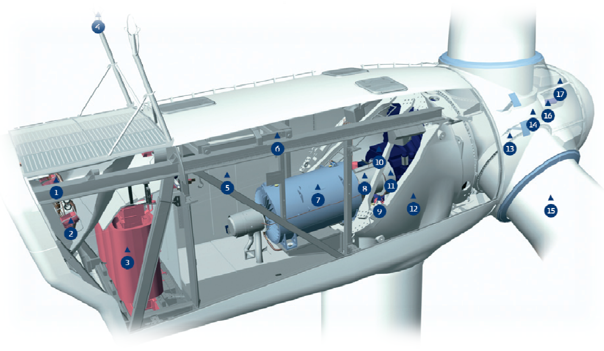
Project	*Country*	*Power*	*Turbines*
Thornton Bank	Belgium	300	Repower 5M
Greater Gabbard	UK	504	Siemens 3.6
Borkum West	Germany	400	Multibrid M5000
Butendiek	Germany	288	Siemens 3.6
Horns Rev	Denmark	160	Vestas V80 (2MW)
Nysted	Denmark	165.6	Siemens 2.3
Egmond aan Zee	Netherlands	108	Vestas V90 (3MW)
North Hoyle	UK (Wales)	60	Vestas V80 (2MW)
Kentish Flats	UK	90	Vestas V90 (3MW)
Burbo Bank	UK	90	Siemens 3.6
Barrow	UK	90	Vestas V90 (3MW)
Scroby Sands	UK	60	Vestas V80 (2MW)

Table 1.13. Largest existing and planned offshore wind farms and turbine model

There are two manufacturers with a clear business volume and experience advantage in offshore wind farms among the leading group. They are Vestas and Semnes and we have focused on their star product.

Some basic information on the Vestas and Siemens big offshore turbine is compiled in the next pages.

VESTAS V90



	V90
ROTOR	
Diameter	90 m
Area swept	6.362 m^2
Operational interval	8.6-18.4 rpm
Number of blades	3
Power regulation	Pitch
Brake	Air brake, full blade pitch by 3 separate hydraulic pitch cylinders

TOWER	
Hub height	80 m

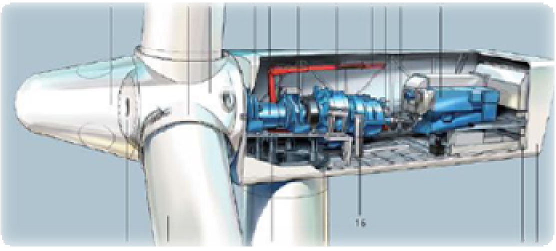
OPERATIONAL DATA	
Cut-in speed	4 m/s
Nominal wind speed	15 m/s
Cut-out speed	25 m/s

GENERATOR	
Type	Asynchronous
Rated Output	3.000 kW
Operational data	50 Hz 1.000 V

WEIGHT	
Rotor	41 t
Nacelle	70 t

Figure 1.12. Technical brochure on the Vestas V90 turbine

Siemens SWT 3.6



	SWT 3.6
ROTOR	
Diameter	107 m
Area swept	9.000 m^2
Operational interval	5-13 rpm
Number of blades	3
Power regulation	Pitch
Brake	Full span pitching. Active, hydraulic
TOWER	
Hub height	80 m
OPERATIONAL DATA	
Cut-in speed	3-5 m/s
Nominal wind speed	13-14 m/s
Cut-out speed	25 m/s
GENERATOR	
Type	Asynchronous
Rated Output	3.600 kW
Operational data	Variable frequency 690 V
WEIGHT	
Rotor	95 t
Nacelle	125 t

Figure 1.13. Technical brochure on the SWT 3.6 turbine

1.5.2. Layout Alternatives

In parallel to the turbine selection, two kinds of distributions have been studied. Nowadays, the WAsP program let a researcher a fast output calculation. The complexity grade is in the definition of layout alternatives.

There are some famous experts in offshore layouts, who usually focus the analysis in one or both of two ideas:

- Trying to get the better solution in terms of economic yield, combining a turbine cost model and a wake model in conjunction with an optimization routine. Factors such as operation and maintenance (O&M), availability and electrical interconnection models also play significant roles in the design of an offshore. Among others, a investigation group of the Mechanical and Industrial Engineering Department, at the University of Massachusetts is developing a Offshore Wind Farm Layout Optimization (OWFLO) project., wind farm

- Researchers Rebecca Barthelmie, Gunner Larsen and other Swedish team mates are, with the project ENDOW (Efficiency Development of Offshore Windfarms), a world reference in evaluation and prediction of offshore wake models, using new and updated databases from existing offshore wind farms and detailed wake profiles collected through a sodar.

The models developed by these and other researchers vary in complexity from empirical solutions to the most advanced models (based on, in the case of the second bullet, solutions of the Navier-Stokes equations using eddy viscosity combined with a kepsilon turbulence closure), but all of them forms the basis of design tools for use by wind energy developers and turbine manufacturers to optimize power output and profits from offshore wind farms.

In the current project, taking into consideration the database analysis (the wind direction conclusions, mainly), the low roughness on sea bed (what multiplies the wake effect) and the recommendations on turbines separations due to those, some ideas have been respected when defining the layout alternatives:

- The minimum separation between two turbine sites needs to be equal or larger to a given number of rotor diameters.
- In the predominant wind direction, the wake effect can reduce in a sensitive way the energy output. Therefore, in this direction the separation should be even bigger. A value of eight rotor diameters is well considered by many authors.
- Considering logistics costs, in the commissioning but also in operation and maintenance (O&M) the proportion between the perimeter sides of the wind farm surface must be reasonable.
- In the North Sea, in the studied coordinates, there is lack of obstacles; therefore the turbines should be spread in a regular way.

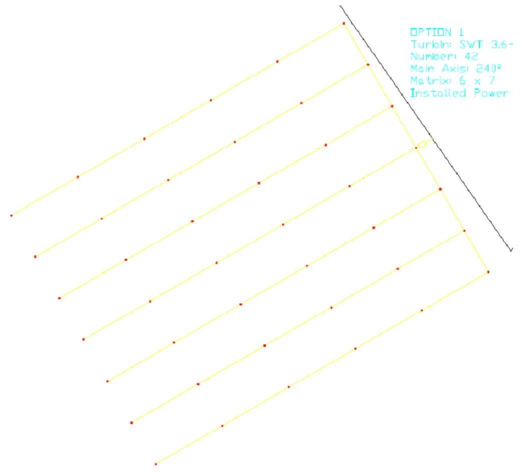
With these ideas, some rules have been established in the creation of alternatives:

- Each alternative of layout is composed of rows and columns.
- The rows and columns are sized in a way the wind farm has a regular shape of rectangle.
- The minimum proportion between width and length must be ¾.
- Two straight turbines cannot be closer than 5 rotor diameters.

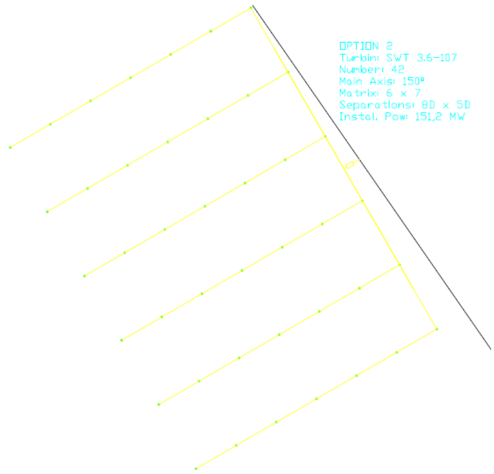
- Al least one of the proposal with each turbine model has to be aligned in a way the rows are parallel to the main wind direction sector.
- At least there must be two alternatives for each turbine model.

With these constraints, four alternatives have been built, as follows.

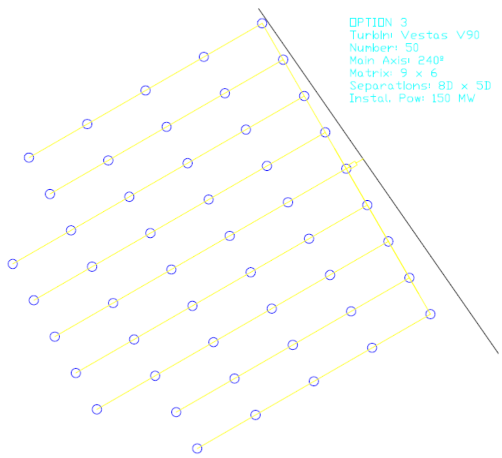
1. 42 SWT 3.6 turbines, for a installed power of 151.2 MW, in a 6*7 matrix, with 8 rotor diameters separation in the parallel axis to the main wind direction sector



2. 42 SWT 3.6 turbines, for a installed power of 151.2 MW, in a 6*7 matrix, with 8 rotor diameters separation in the perpendicular axis to the main wind direction sector



3. 50 V90 turbines, for a installed power of 150 MW, in a 9*6 matrix (with 4 empty locations), with 8 rotor diameters separation in the parallel axis to the main wind direction sector



4. 50 V90 turbines, for a installed power of 150 MW in a 9*6 matrix (with 4 empty locations), with 8 rotor diameters separation in the perpendicular axis to the main wind direction sector

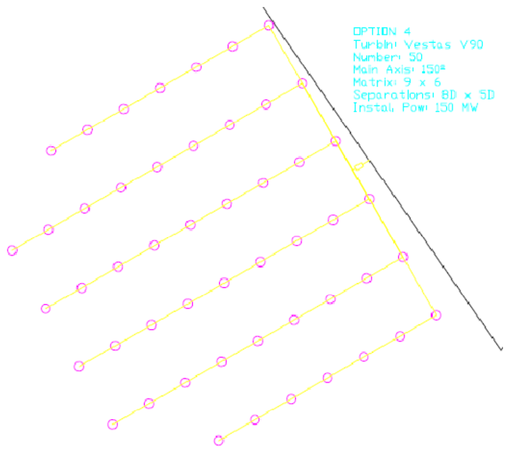
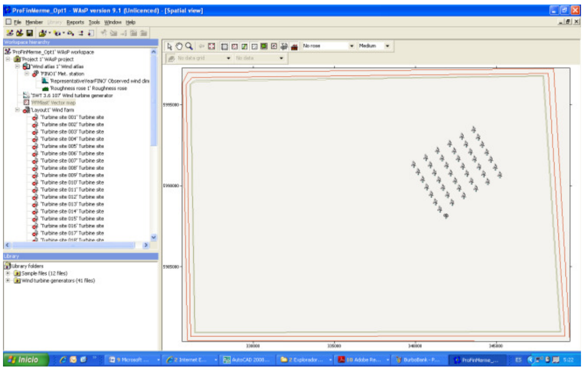


Figure 1.14. Characteristics and scheme of the four layout alternatives proposed.

1.5.3. Best Layout Alternative Selection

Before calculate the annual production of each one of the described alternatives, it has been necessary to follow the next steps:

- Obtain the power curve from the manufacturer.
- Create a vector map with information on the roughness, orography and coordinates framework.
- Generate a wind atlas of the whole location.
- Lay the meteorological station position (X and Y coordinates as well as height).
- Import the coordinates of the turbine sites for each alternative (in total, 184 sites are managed).



With all these inputs, WAsP can be run, giving this way the results on the wake effect and the mean at each turbine site, as well as the productivity of all the wind farms turbines, all parameters given by sectors of direction and in total.

Finally, the result of output by each alternative gives a solution.

(MWh)	Option 1	Option 2	Option 3	Option 4
Net AEP	555874.255	553423.34	555269.603	553205.3

Table 1.14. Net AEP calculated for the four alternative layouts.

Thus, the choice, based on a production criteria, is the first option:

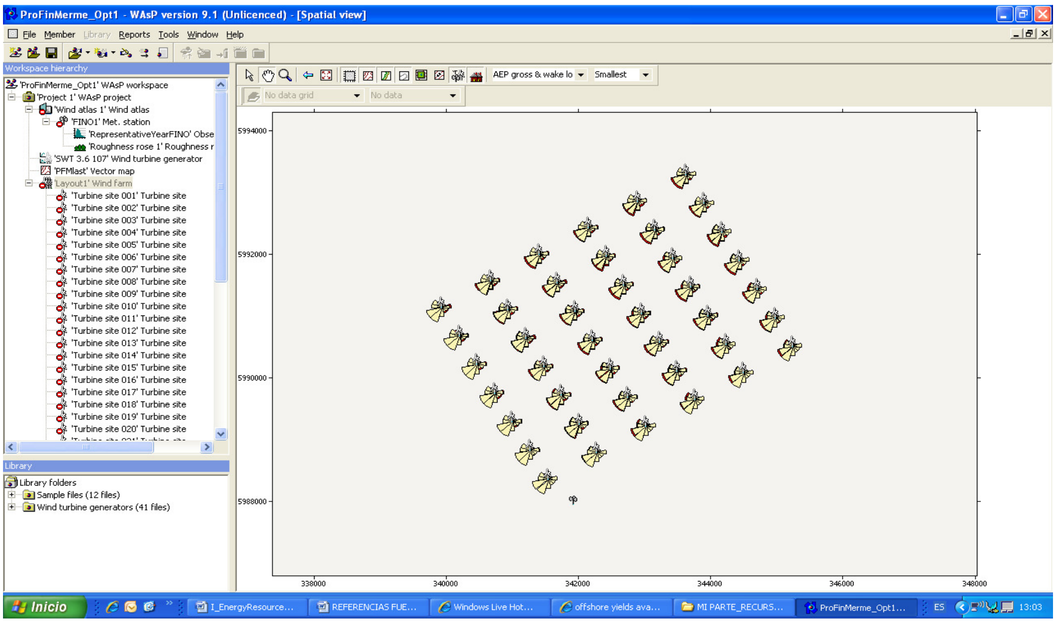
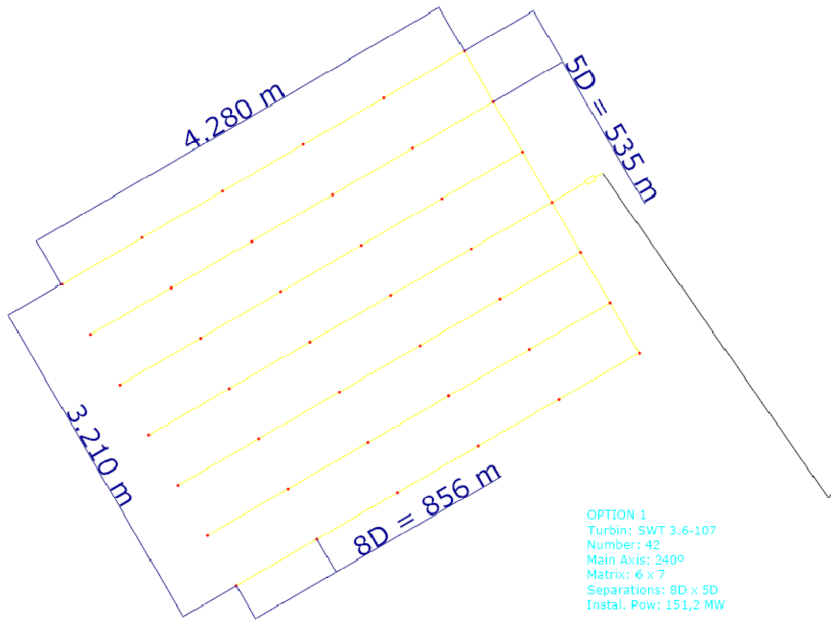


Figure 1.15. View of a WAsP program operative window

1.5.4. Summary of the wind farm layout

The Figure 1.16 compiles some of the main information on the selected wind farm layout.

Installed power(MW)	151.2 MW
Turbine model	Siemens SWT 3.6-107
Number of Turbines	42
Number of rows	6
Row size	7
Main (Wind) Direction	240º
Main Direction Separation	8D
Separation between rows	5D
Net Annual Energy Production (MWh)	555.874,255
Annual Equivalent Hours	3676,42



4 corners UTM– X(m)	339.938,89	343.642,64	341.547,56	345.251,32
4 corners UTM– Y(m)	5.991.143,48	5.993.288,38	5.988.365,66	5.990.510,56

Figure 1.16. Main characteristics of the selected layout option

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1.6.1. Bibliography

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1.6.2. Internet References

All the links listed below have contributed in a certain way to the realization of the present document. Some sources have been used directly to add some information, all of them to learn offshore concepts.

- http://192.107.92.31/test/owemes/17.pdf
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- http://en.wikipedia.org/wiki/North_Hoyle
- http://en.wikipedia.org/wiki/Vestas_V90-3MW
- http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?tp=&arnumber=4581308&isnumber=4581062
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- http://www.paginaenergiasrenovables.com/forosmf/index.php
- http://www.pc-control.net/pdf/022008/pcc_0208_multibrid_e.pdf
- http://www.powergeneration.siemens.com/products-solutions-services/products-packages/wind-turbines/offshore/
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- http://www.repower.de/fileadmin/download/produkte/RE_PP_5M_uk.pdf
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- http://www.wind-energy-market.com
- http://www.windpower.org/es/pictures/offshore.htm
- http://www.woeurope.eu/weather/maps

2. FOUNDATIONS & INSTALLATION

CONTENTS

2.1 FOUNDATIONS

2.1.1. INTRODUCTION

The main difference between an onshore and an offshore wind farm is not the wind conditions neither the turbines but the foundations. Foundations represent the key challenge in the offshore wind energy development. Despite wind energy sector is already mature and one of the most innovative industrial sectors still lacks of knowhow regarding foundations and installations offshore.

As onshore wind turbine foundations cannot be transplanted into the marine environment we have seen the evolution of different foundation types. Here existing fields of expertise have attempted to adapt their technology to the new industry of offshore wind. Mainly the oil and gas and the marine construction industries have developed very different solutions because of the different support requirements.

These "tailor made" solutions make this part of the project to be very resource demanding in terms of funding and infrastructure and equipment availability. In comparison to an onshore wind farm expenditures where the turbines represent about 75% of total costs and foundations a mere 5%, the costs of offshore wind farms are made up of a 57% due to turbines and 16% because of the foundations among other expenditures. (See charts below)

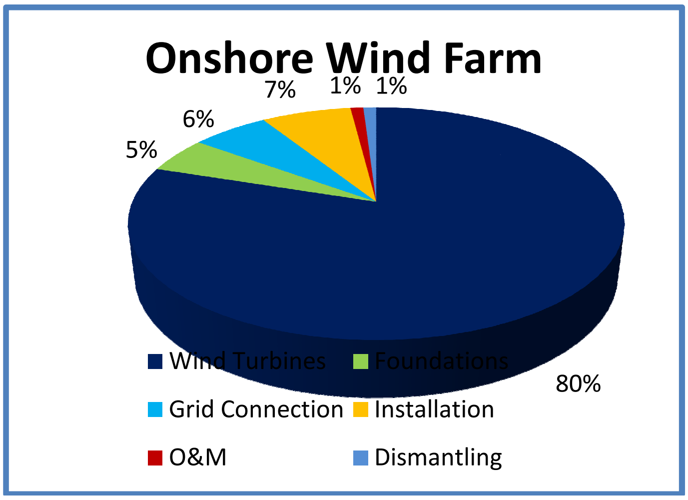

Figure 2.1 Cost breakdown of an onshore wind farm

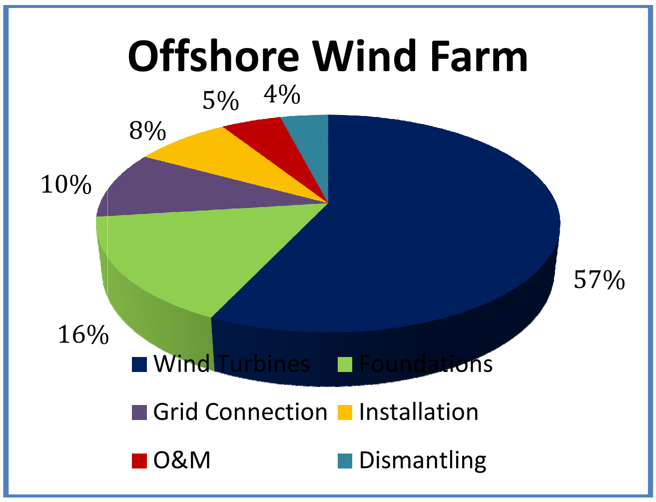

Figure 2.2 Cost breakdown of an offshore wind farm

The charts show the great importance that foundations gain in offshore wind development in comparison to onshore wind farms.

In addition to the cost of the foundations, another key issue is the time and equipment needed for their installation -already reflected in the cost-, hindering the management of the overall project.

These aspects and some more will be taken into account in the following suitability analysis of the foundations for this project. Always having in mind the goal of reducing costs different parameters will be analyzed, weighted and discussed in the following points. These are such as soil conditions, bathymetry, sea conditions (roughness), and the technology available up to date and once the choice will be made and structural analysis will be carried out considering the loads and stresses it will suffer during its lifetime.

2.1.2. ELECTION OF THE FOUNDATION TECHNOLOGY

There are several parameters that condition the choice of a certain type of foundation. Most of them depend on the conditions of the site location. Therefore the initial step is to determine the seabed's composition and the water depth. Once known these features, other parameters will be considered in order to get the optimum balance and find the foundation that best suits for this project.

2.1.2.1. Seabed conditions

The North Sea is one of the better areas worldwide for the development of offshore wind energy. The water depth is relatively low in many regions as to be able to allocate wind farms and the wind conditions are really good for producing energy enough to make it economically feasible. For the most part, the sea lies on the European continental shelf with a mean depth of 90 meters. The only exception is the Norwegian trench which extends parallel to the Norwegian shoreline from Oslo to an area north of Bergen. It is between 20 and 30 kilometers wide and has a maximum depth of 725 meters. The Dogger Bank, a vast moraine, or accumulation of unconsolidated glacial debris, rises 15 to 30 meters below the surface of the sea.

Much of the sea's coastal features are the result of glacial movements. Deep fjords and sheer cliffs mark the Norwegian and parts of the Scottish coastline, whereas the southern coasts consist of sandy beaches and mudflats. These flatter areas are particularly susceptible to flooding, especially as a result of storm tides.

2.1.2.1.1. Bathymetry

Although bathymetry maps are fully developed for the North Sea, a local study may be needed in order to gather as much information as possible just in case that really detailed information is needed for some type of foundation such as gravity foundations, which necessitate seabed preparation before being weighted down.

Going from more general information to more detailed one is the common way of analyzing the suitability of a location.

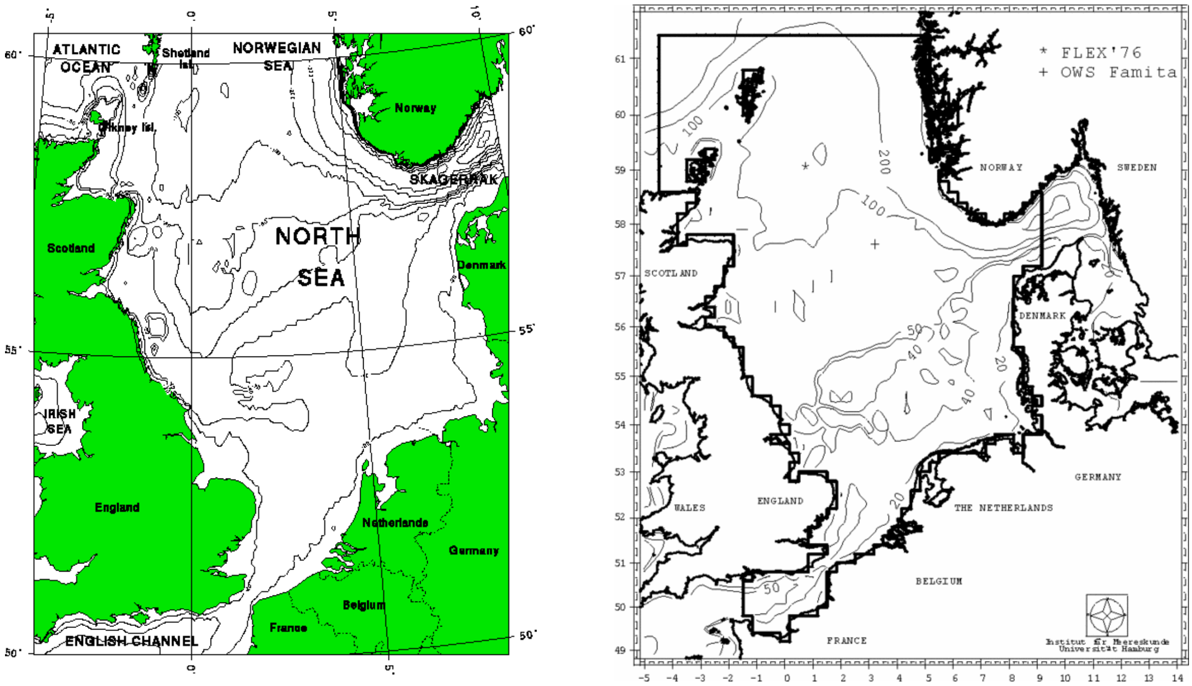

Figure 2.3 North Sea bathymetry

In this particular case the wind farm will be allocated within the German Exclusive Economic Zone (EEZ), close to the Netherlands' EEZ. The area is called Borkum after the biggest island close to it. Three different areas were selected as valuable areas for wind energy development due to the favourable bathymetry and compatibility with marine shipping routes and undersea infrastructure (piping and wiring mainly). These areas are marked in red in the chart below.

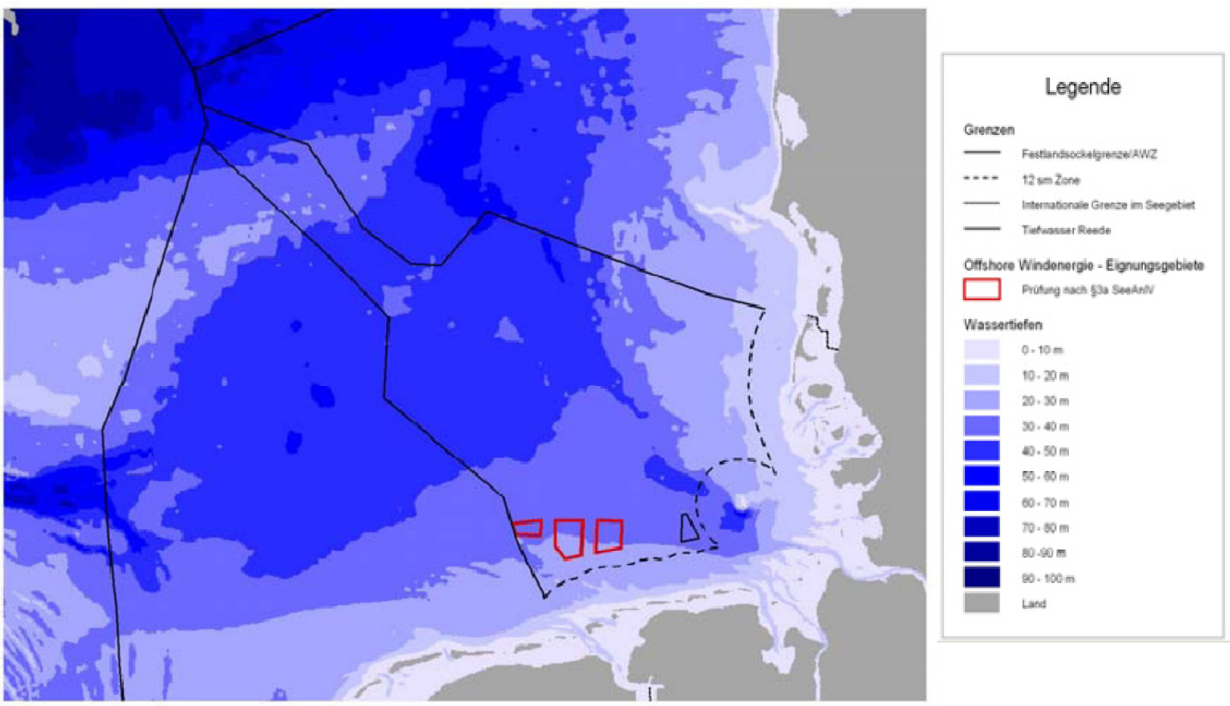

Figure 2.4 North Sea bathymetry and potential areas to develop offshore wind farms (Source: BSH)

As it is shown in the map, the three mentioned regions are allocated in th e limit where the water depth is around 30 meters. In the south part of zone II (the one in the middle in the picture) the seabed is completely in the 20 to 30 meters water depth and there is where the wind farm will be placed.

A more detailed bathymetry map was developed by the Bundesamtes für Seeschiffahrt und Hydrographie (BSH).

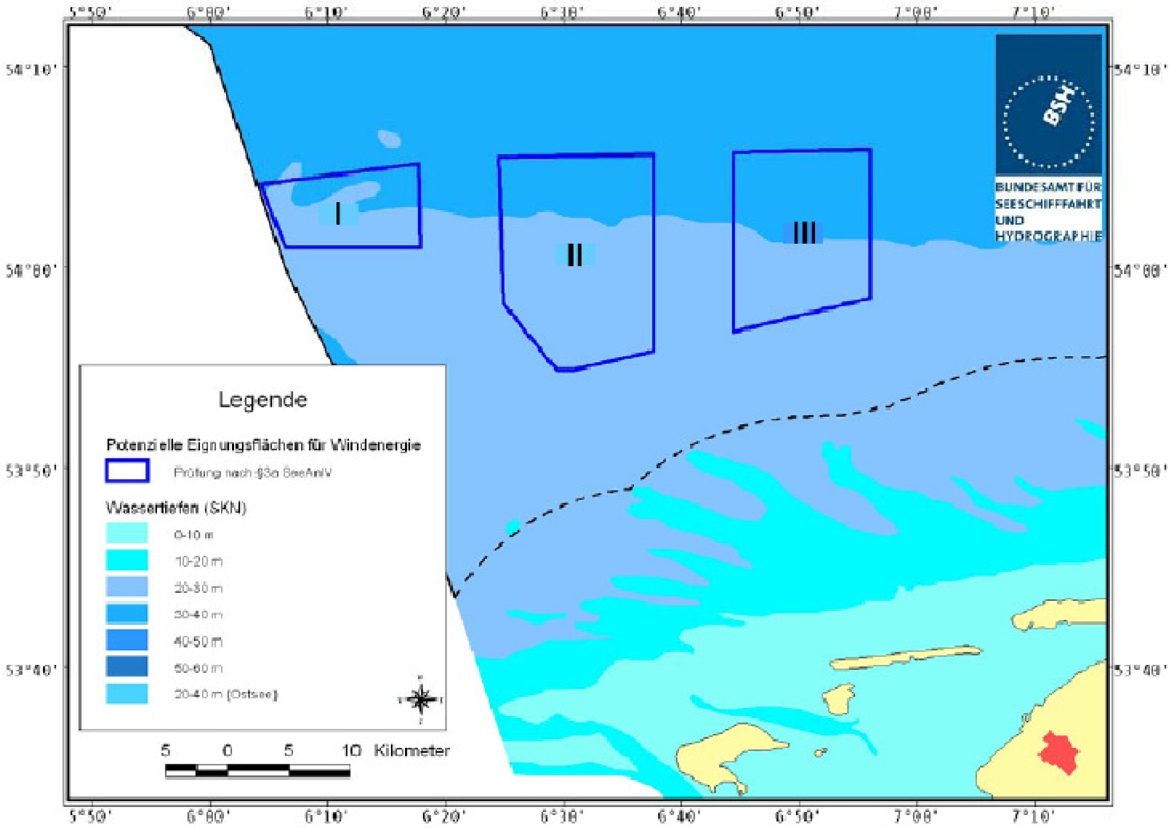

Figure 2.5 Detailed bathymetry of Borkum area

As a conclusion of the bathymetry studies it is fair to say that the foundations will be placed in a region where the water depth lies between **25 to 30 meters**.

2.2.1.2. Soil composition

The water depth in these particular valuable areas lies between 23 meters in the Southeast and 33 meters in the North. The seabed is relatively flat with the exception of isolated large ripple sediment fields.

In Fig. 2.6 is represented the sediment distribution rule for the three valuable areas which consists predominantly of fine and medium sands and goes over in western direction to the Borkum sandbank becoming coarse sand. The fine grain (silt and clay) lies as a rule representing less than 5 weight per cent. From the current perspective on the seabed knowledge no stones, stone fields, queuing boulder clays or reefs appear in the sea bottom.

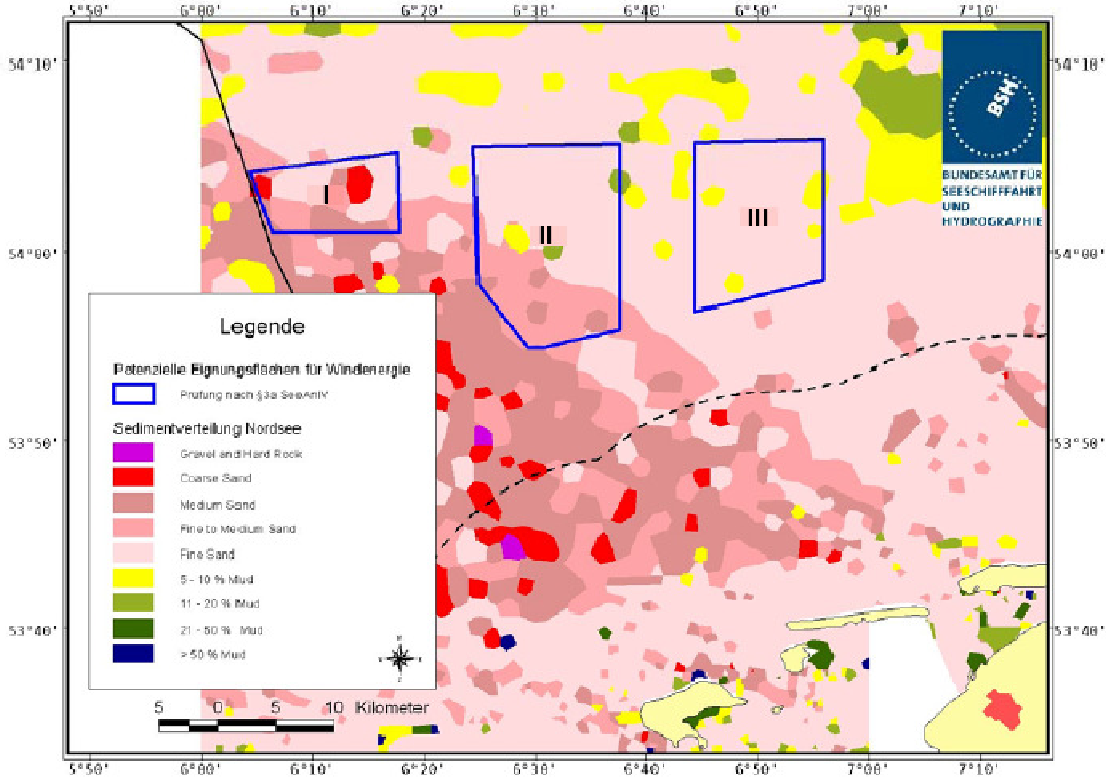

Figure 2.6 Sediment distribution within the studied area

The area is generally characterized by a three-ply layer construction in the subsoil. Under the mobile sandy layer lies approximately 10 to 40 meters of a powerful layer from the ice-age made up of fine sand to coarse sand which is deposited again on boulder clay which in some places up to 65 meters under the sea bottom can lead to large stones and blocks (erratic blocks). Melted snow and ice rivers have incised during the ice age into its highly turbulent surface, explaining why the filling material show a heterogeneous sediment composition of fine grain to gravel. It is also expected to find peat layers in some locations. These old channels fill meanders in the subsoil, but they are geographically limited.

Valuable Area I

The area covers 93.8 km ^{2}. The water depths reach depths of 23 meters in the southeast and increase to the north up to 33 meters.

The area is situated on the seaward extension of the actual Borkum sandbank which represents the undersea continuation of the East Frisian ridge. The sea bottom shows here a more heterogeneous sediment distribution which goes over from the fine sand in the NE to the medium to coarse sand in the SW. 11% of the surface is made up of coarse sand, 20% of medium grain sand, and 68% of the (medium sandy) fine sands. All deck sand found in this partial surface show a fine grain composition of less than 5 weight percent.

After the results of flat drillings (up to 3 meters of penetration) and seismic profiles the average thickness of the North Sea temporal sediment layer varies between 1.5 meters and 2.5 meters where the coarse sand surfaces are thin in the area or completely lacking.

Within the partial surface I no deep well is present. Approximately 6 kilometers southerly on the Borkum sandbank, within the framework of a research drilling of 30 meters, hard ice-age sand appears. Besides, they were found medium to coarse sands in the upper 2 meters. The deeper horizons consist mainly of the ice-age fine sand.

Valuable Area II

The area covers 256.5 km ². The water depths reach depths of 23 meters in the southeast and increase to the north up to 33 meters.

In this partial surface the sea bottom shows a weakly homogeneous sediment distribution from the fine sands in the NE to the medium sands in the SW. Locally, 4% of the surface is composed of the fine sand silt and clay up to 20 weight percent. Remaining 96% of the surface are dominated by the fine to the medium sands with a fine grain less than 5 weight percent.

After the results of seismic profiles the average thickness of the North Sea temporal sediment layer varies between 1.5 meters and 2.5 meters.

In the eastern area of the partial surface II a drilling is present, which was brought down for the establishment of the research platform "FINO 1". Thereafter, the upper 32 meters of the sea bottom are built up from the ice-age fine to medium sand. Five kilometers to the east of the partial surface a research drilling up to 200 meters under the seabed proved that the first 8 meters consist of ice-age sand and under it a profile of 65 meters of loam or marls deposit lays.

Valuable Area III

The area covers 192 km ². The water depths reach depths of 24.5 meters along the south border and increase to the north up to 33 meters.

In this partial surface the seabed shows a homogeneous sediment distribution which consists mainly of fine sands. Locally, 8% of the surface is made up of fine silt and clay sand up to 10 weight per cent. Remaining 92% of the surface is dominated by fine sands with a fine grain with less than 5 weight percent.

After the results of flat drillings (up to 3 meters of penetration) and seismic profiles the average thickness of the North Sea temporal sediment layer in area III is approximately 2.5 meters.

On the south border two research drillings to approximately 40 meters of depth (depth under seabed) are present. Besides, silty fine sand to coarse-sandy medium sand were found. In the upper 10 meters clay layers up to 2 meters of thickness can interrupt locally this sandy series. In the north-east corner descriptions of two other core research drillings of 35 or 40 meters of depth are present. There were also up to 40 meters of ice-age sand deposited in the base area on at least 2 meters of hard gravel layer. There is a 200 meters research drilling 2.5 kilometers to the west of the partial surface III which sows the sane soil composition as in partial surface II.

2.2.1.3. Conclusions

The studied region comprises three potential areas in order to install the projected wind farm. Since the platform FINO 1 is established in the valuable area II, and all the meteorological data was acquired from it, that will be the selected one.

According the previous studies, the wind farm will be set up in an specific area where the water depth varies between 23 and 33 meters. However, the area covers a too large surface in relation to the project size. Therefore the wind farm will be settled in the southeast corner, closer to terra firma and shallower than the rest of area II.

On the other hand, soil conditions are quite similar all across the studied region. The sediment layer, which varies between 1.5 and 2.5 meters thick, is made up a 4% of fine to medium sands with 20 weight percent, and the remaining 96% with 5 weight percent. Besides, the upper 32 meters also consist on fine and medium sands from the ice-age period.

To sum up, the soil conditions within the selected area are 23 to 30 meters of water depth and two subsoil layers. Sediment layer is between 1.5 and 2.5 meters thick and the one below is made up of fine and medium sands up to 32 meters depth below sea level.

2.1.2.2. Available technologies

Several solutions for offshore wind turbines support have arisen during the last years due to the different conditions existing on the different sites.

Due to the lack of expertise in this field of the wind energy industry, others have taken part in this issue. These which already have that expertise are the oil and gas industry and marine construction industry. They have developed many different solutions depending on their own background and knowhow and also the site conditions.

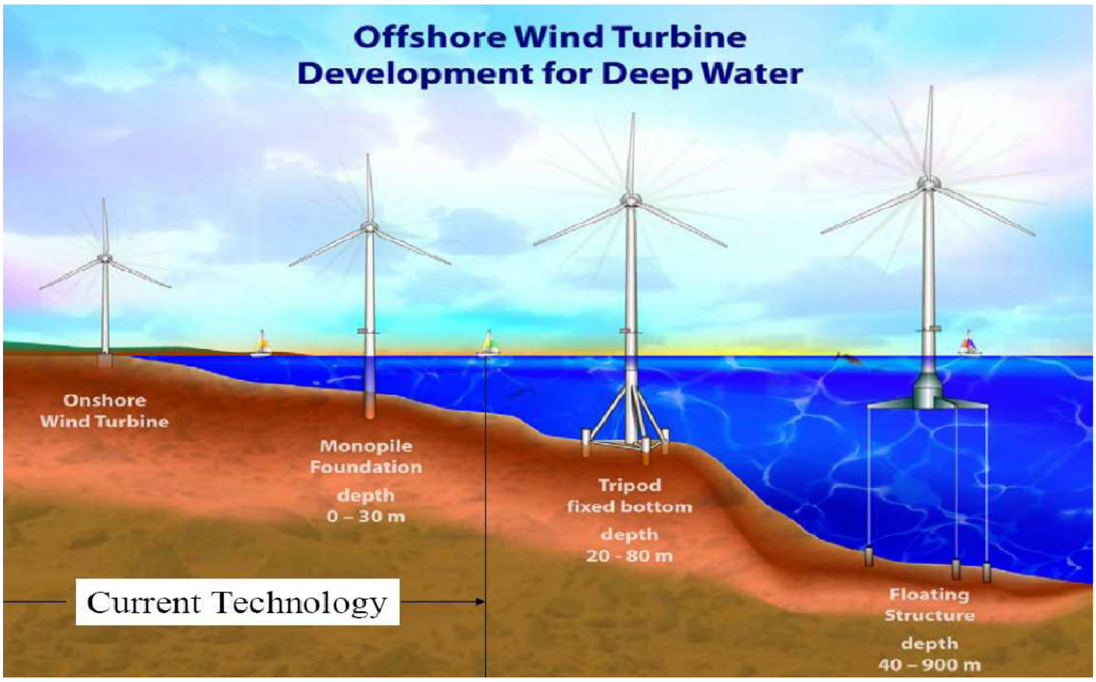

Figure 2.7. Support technologies according to water depth

The main type of foundations currently used or developed as prototypes will be reviewed in the following points.

2.1.2.2.1. Gravity foundations

This generic heading covers a number of techniques. Conventional gravity systems have been imported from both shallow oil and gas and bridge building fields.

The foundations are built onshore near the proposed site using reinforced concrete, then either floated or carried out to their designated position. They are then placed and weighted down with ballast (sand, gravel, and iron ore) to achieve their full design weight. Ice protection can be incorporated into the form of the foundation (in the conical shape of the foundation). As a rule the mass of concrete is approximately proportional to the water depth squared. Scaling these foundations means they become prohibitively heavy and expensive in water deeper than 10m.

In answer to these limitations designers have developed gravity base utilizing steel for its primary strength. The OWEC is mounted on a large diameter steel tube which sits on a very large steel base (typically about 14 m diameter). The structure is placed and weighted down in the same way as the conventional method. The large weight saving means conventional equipment can be used for transport and placement, significantly extending the range of economic water depths. These gravity bases offer the contractors the possibility of partial assembly of the OWEC prior to transportation to site. The fewer number of operations carried out at sea the cheaper the installation, this is true for both piled and gravity foundations.

The main drawback to gravity bases is their size; this necessitates manufacture close to the wind farm site. It also relies on detailed logistical planning of the preparation and installation of the bases. Installation times must take into account sea bed preparation, this is essential in order to achieve a level surface and sufficient bearing capacity for the foundation. Many of these activities have to be concurrent to avoid delays; this places a big responsibility on planners to prevent conflict and possible dangers with different contractors.

Seabed erosion (scour) can be an issue with these large diameter bases. It is prevented with the placement of boulder curtains around the base of the foundation. This is an underwater operation requiring divers, and is an additional cost penalty to sites where scour is prevalent.

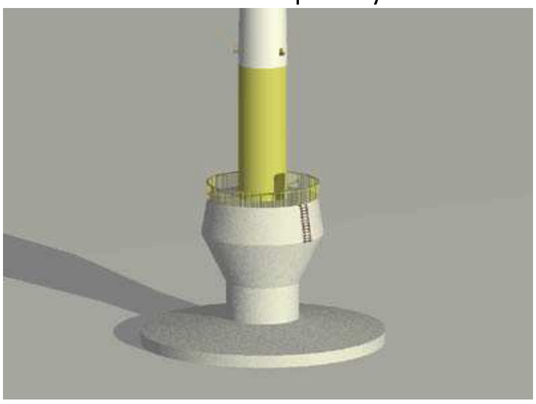

Figure 2.7 Gravity foundation - 3D model

Figure 2.8 Concrete gravity foundations at Lillgrund, Sweden

In order to solve the main limitation of these type of foundations, cost-effectiveness on deeper water, many other designs are being developed although none of them has been tested yet. Some of these prototype designs are showed in the following figures:

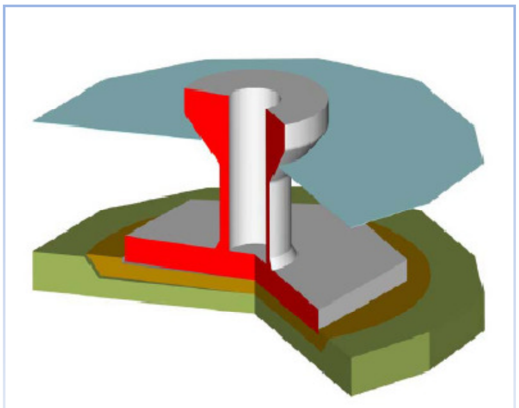

Figure 2.9 a) Conventional gravity foundation with ice-cone-top (5 to 10 m depth)

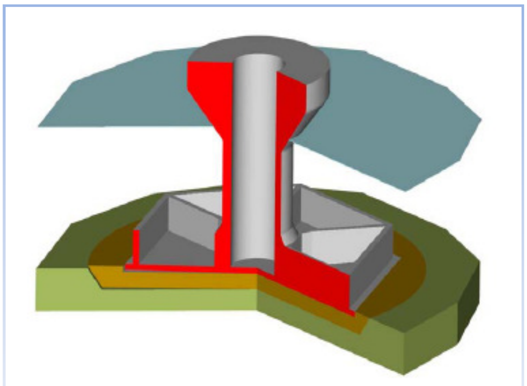

Figure 2.9 b) Conventional GF with ice-cone-top and ballast chambers (5 to 10 m depth)

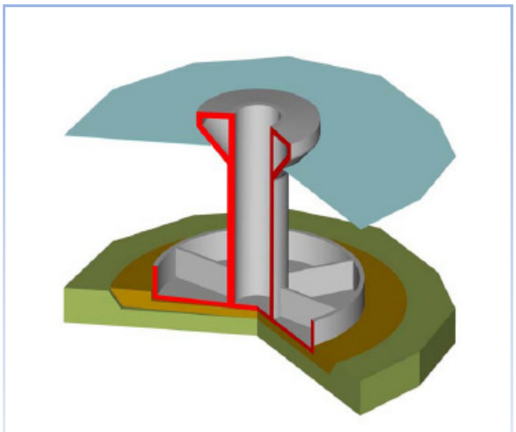

Figure 2.9 c) Conventional GF with ballast chambers (reduced weight) (5 to 15 m depth)

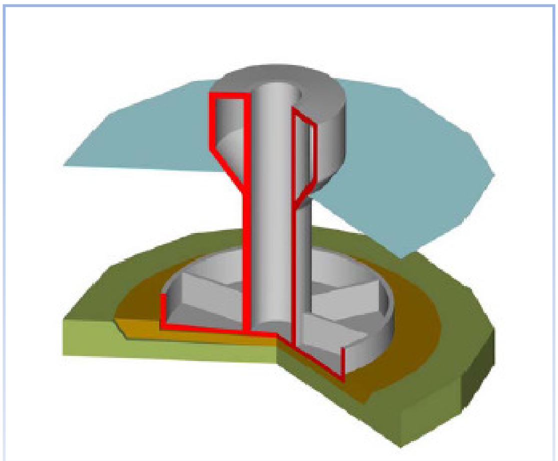

Figure 2.9 d) Conventional GF with enlarged chambers (reduced weight) (5 to 15 m depth)

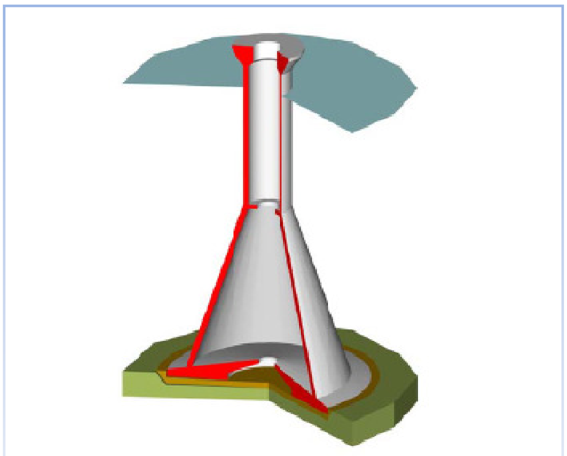

Figure 2.9 e) Deep water GF with internal ballast chamber and piles (25 to 40 m depth)

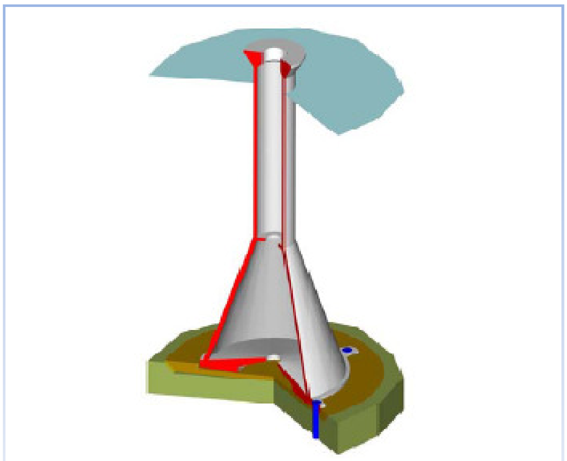

Figure 2.9 f) Deep water GF with internal ballast chamber (20 to 35 m depth)

2.1.2.2.2. Piled foundations

Here existing fields of expertise have attempted to adapt their technology to the new industry of offshore wind. The oil and gas industry have offered structures consisting of jackets with securing piles driven into the seabed. Generally they use small diameter piles. The marine construction industry has offered structures similar to those used in jetties and mooring dolphins. Generally they use larger diameter piles.

Notably the above disciplines have developed very different solutions because of the different support requirements. Oil and gas structures have to carry high dead loads due to the mass of the topsides, but lesser live loads from wind and waves. Whereas harbour structures such as mooring dolphins have only their self weight but must be designed to withstand high lateral loads from shipping producing large bending moments.

Because of the above and limited water depth, existing sites have favoured foundations derived from the construction industry.

Within these range of piled foundations, the more developed ones are the following:

- ✓ **Monopile**

The monopile is the simplest of piled foundations and used with OWECs acts as an extension of the tower down into the seabed.

A monopile is the most cost-effective foundation type for offshore wind energy conversion systems. Due to its simple global design, it is the preferred solution in areas with water depths up to 25 m and soil consisting of mostly sand. Since it cannot bear great horizontal forces and moments because of its small lever arm, its global stiffness is generally rather low, and does not develop much resistance in case of ship collisions.

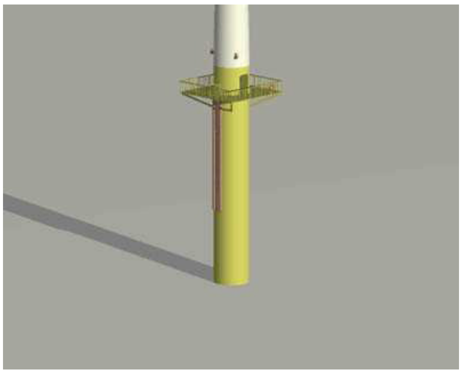

Figure 2.10 Monopile foundation - 3D model

If bed rock is not encountered at the desired piling depth alternative methods of installation are applicable. When the overburden consists of soils i.e. sands, gravels, clays – the pile can be driven to depth using a variety of means. This can be a hammer system using diesel or hydraulic power; or vibrator or oscillator. In general these methods are quicker than drilling but are limited by site conditions. The driving process induces high fatigue stresses in the pile, which prevents incorporation of ladders, platform, flange etc. in the pile fabrication. They have to be provided separately and fitted as additional operations, thus reducing many of the time benefits of driving.

Another alternative is the combination of drilling and driving, this is merely a combination of the above. The driving equipment is substituted for a drill when the prevailing ground conditions are no longer favourable. This system tends to fall between the others in terms on speed.

One advantage of piling is that there is no need for seabed preparation (except where seabed erosion is a problem) this removes to need for time consuming underwater preparation. The main obstacle to all of the above methods is boulders; they greatly hinder progress and may cause damage to the pile itself.

Piles can be steel, concrete or composite, in OWEC foundations this is dominated by steel. This is because its strength to weight ratio far out weighs concrete, reducing the scale of equipment necessary for installation. Referring to the above load cases, it is also far better at resisting bending and tensile loads. As OWECs venture into deeper waters these attributes will be critical to the economics of the foundation.

Figure 2.11 Q7 Wind farm monopile model

Figure 2.12 Q7 Wind farm with monopile foundations

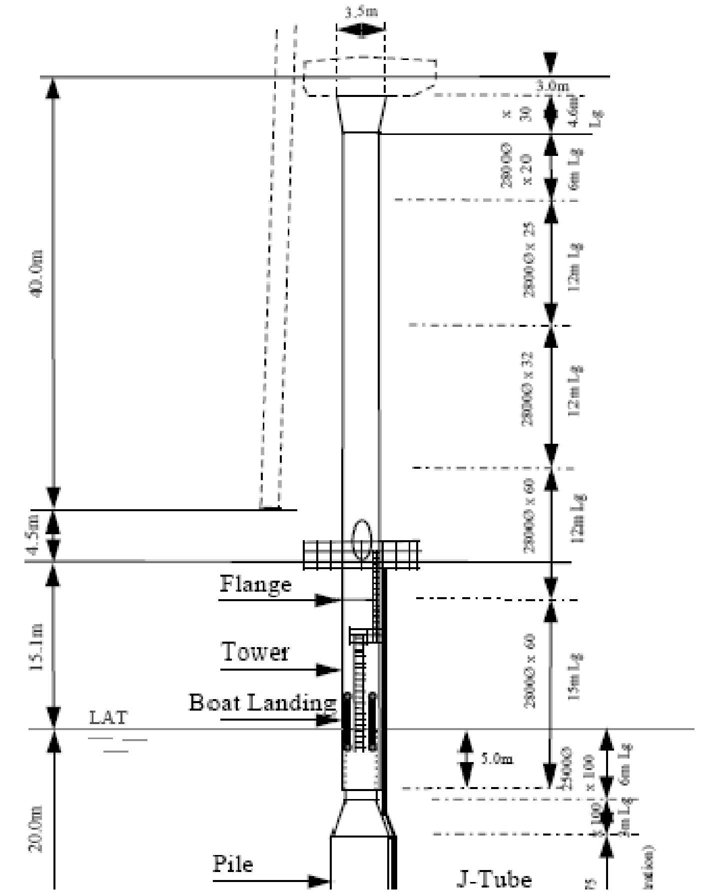

Figure 2.13 Monopile - Parts breakdown

✓ Tripod

Although monopiles have been the preferred choice over other piled foundations at shallow water sites their geometry is less favourable in deeper water. This has led designers to consider alternative structures more resembling jackets, typically these "tripods" consist of a centre large diameter tube with three supporting legs which are individually secured to the seabed with small diameter piles. This system has been used in the oil and gas fields for secondary installations. Because of their complexity and the requirement to develop fatigue resistant joints they are not competitive with monopiles in shallow applications, their geometry is not well suited to shallow water and the supporting legs hinder boarding by operation and maintenance crews to the OWEC.

Tripods are mostly used in areas with water depths greater than 25 m. The global stiffness of the tripod is comparable to that one of the jacket foundation, but consists of fewer components, which makes it easier to build, and decreases building costs. The local stiffness of the diagonals is much higher compared to those of the jacket, resulting in higher resistance to structural failure.

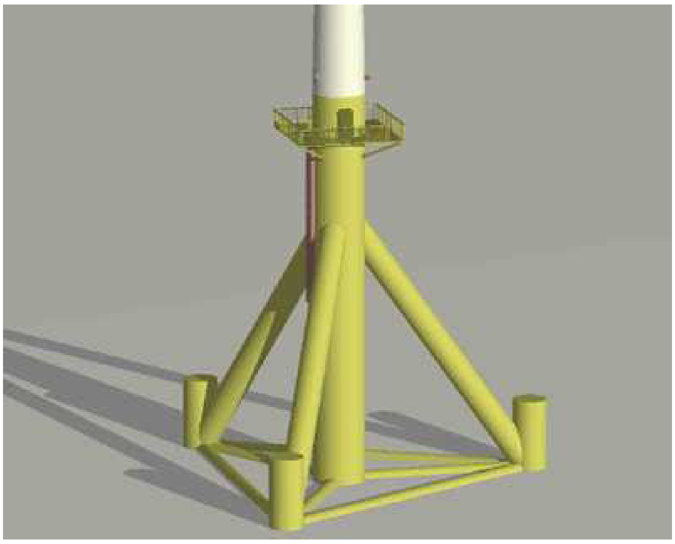

Figure 2.14 Tripod foundation - 3D model

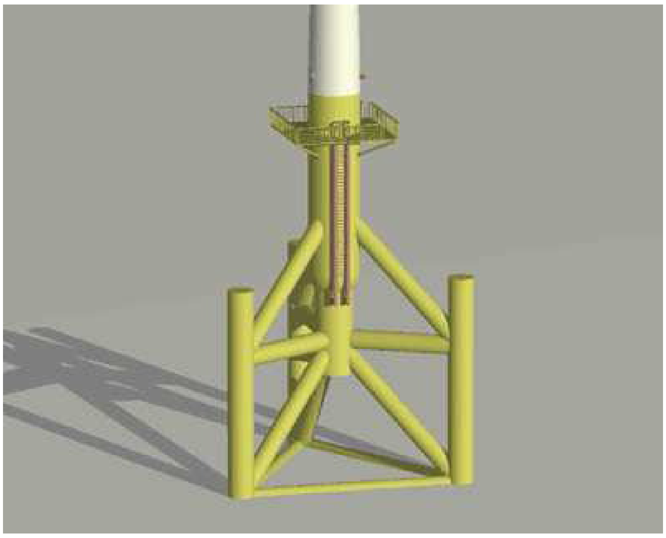

Figure 2.15 Alternative tripod foundation - 3D model

- ✓ **Jackets**

Jacket structures are widely used for offshore applications. A jacket combines high global stiffness with low structural mass. For offshore wind energy however, costs of manufacture and installation seem to be more relevant. It may be used at locations with greater water depths, e.g. more than 25 m and up to 50 m. Due to its large global and small local stiffness, it exhibits a large variation of failure modes during collisions.

It seems to be cost-effective for deeper waters as from 40 meters on. The best example of this support technology is the Beatrice project, in Scotland.

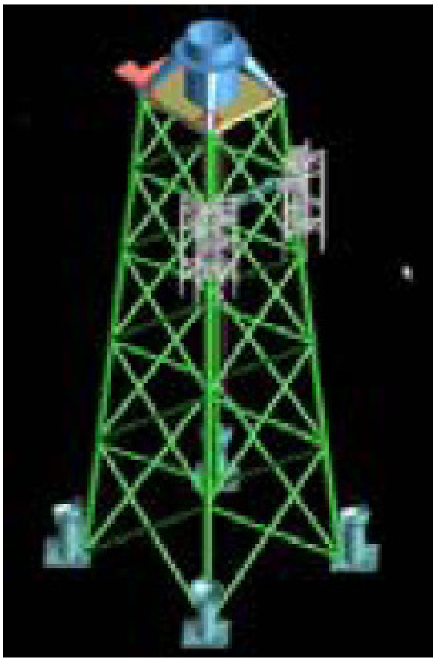

Figure 2.16 Jacket structure used in Beatrice project

Figure 2.17 Jacket structure foundation sketch

✓ **<u>Other piled foundations</u>**

Several other designs have been developed although they are not tested or used so far as the previous ones. Tri-pile, multi-pile, and diverse jacket and tripod designs are within these developing technologies.

2.1.2.2.3. Floating foundations

As to the end of the project one floating support structure is being tested only. The project is been carried out by a Norwegian oil and gas industry company and a wind turbine manufacturer and wind farm promoter. All the designs except for that one are still in an early stage, modeling the floating support structures at different laboratories.

Some of the suggested and studied designs are shown in the following pictures.

Figure 2.18 Floating tripod structure

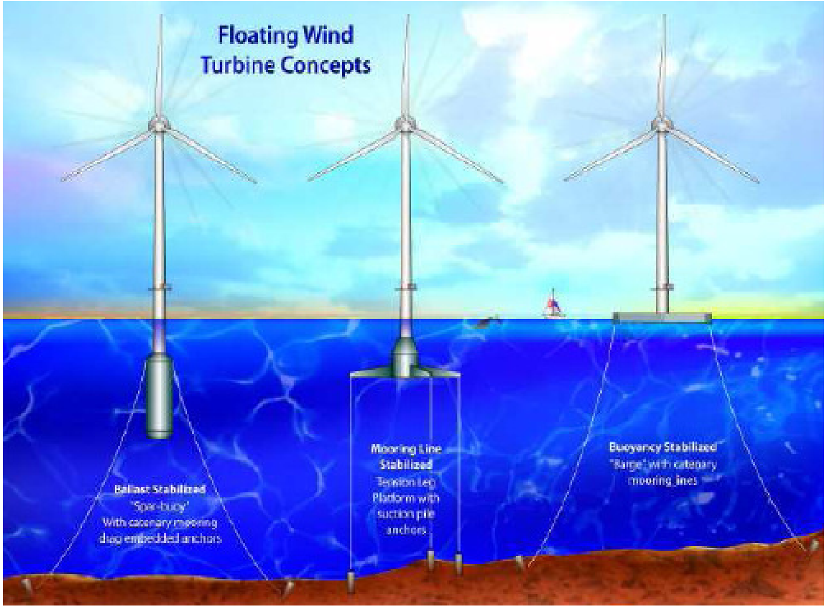

Figure 2.19 Some moored floating designs

Figure 2.20 Stabilized floating support structures

2.1.2.2.4. Conclusions

Once reviewed all the available technologies for offshore wind turbine foundations, the next step is to analyze them and find the more suitable one for the purpose of the project.

The chart below sums up the features of the different technologies taking into consideration their pros and cons, as well as some examples of sites using each one.

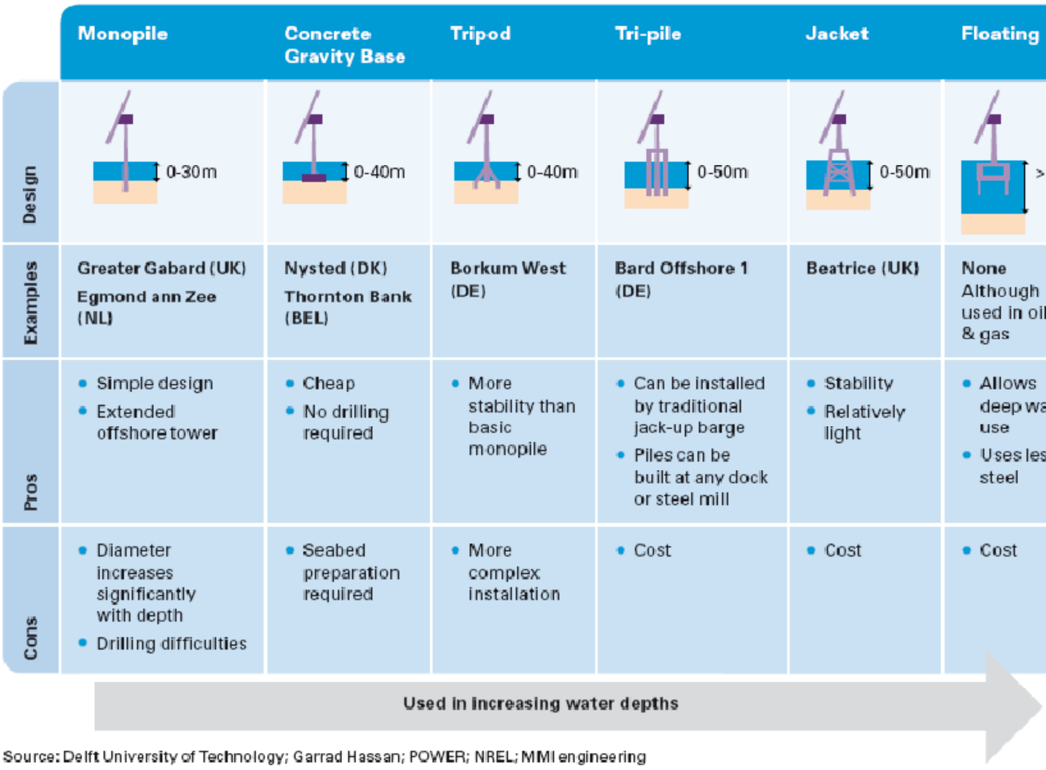

Figure 2.21 Different technologies analysis (Source: Carbon Trust)

Since our project will be placed in medium water depths (23 to 30 meters) and, according to all the wind farms operating so far, there are two main options to consider: gravity foundations and monopile. Despite the rest of technologies are technically feasible since they are thought for deeper waters, the lack of real experiences and the high cost of them are definitive to rule out those options.

Besides the depth and cost, many other aspects have to be considered when making the final decission. The equipment and infraestructure necessary to install the foundations are key to the project success. Also the weather and sea conditions are crutial in order to adapt the installation process to the favourable weather moments.

The expertise and knowhow of the installers is also important in a commercial project. The less time they spent installing the windfarm and the less problems they find the cheaper the project.

In order to make some comparisons between this project and most of the existing wind farms the following table have been built, gathering the most relevant features of each project.

It is easy to see in the table that monopile is the most used option for offshore wind turbines foundation so far. Besides, gravity foundations are commonly used in shallower sites, just up to 10 meters water depth. Leaving aside non-tested foundations for deeper waters, and given that water depth, cost-effectiveness, installation equipment availability and expertise points out to monopile as the most suitable type of foundation for the conditions of the project, the selected type of foundation is driven monopile.

Driven monopile is the type of foundation that best meets the needs of the site in terms of water depth, soil conditions to be installed and cost.

Name	Country	Year	Turbine	No. of Turbines	Unit Power (MW)	Total power (MW)	Hub height (m)	Rotor diameter (m)	Distance from shore (km)	Water depth (m)	Foundation
Vindeby	Denmark	1991	Bonus 450	11	0.45	4.95	37.5	35	1.5 - 3.0	**2.0 - 5.0**	**Gravity-Concrete caisson**
Lely	Netherlands	1993	NedWind	4	0.5	2	39	40.8	0.8	**5.0 - 10.0**	**Driven Monopile**
Tuno Knob	Denmark	1995	Vestas	10	0.5	5	40.5	39	6	**3.0 - 5.0**	**Gravity-Concrete caisson**
Dronten Isselmeer	Netherlands	1996	NEG Micon	28	0.6	16.8	-	-	0.02	**5.0**	**Driven Monopile**
Bocksligen	Sweden	1997	NEG Micon	5	0.55	2.75	-	-	3	**6.0**	**Driven Monopile**
Utgrunden	Sweden	2000	GE Wind	7	1.5	10.5	65	70.5	8	**7.0 - 10.0**	**Driven Monopile**
Blyth	UK	2000	Vestas V80	2	2	4	58	66	1	**5.0 - 11.0**	**Drilled Monopile**
Middelgrunden	Denmark	2000	Bonus	20	2	40	60	76	2	**5.0 -10.0**	**Gravity-Concrete caisson**
Yttre Stengrund	Sweden	2001	NEG Micon	5	2	10	60	72	5	**6.0 - 10.0**	**Drilled Monopile**
Horns Rev	Denmak	2002	Vestas V80	80	2	160	70	80	14 - 20	**6.0 - 14.0**	**Driven Monopile**
Palludan Flack (Samsoe)	Denmark	2002	Siemens	10	2.3	23	61.2	82.4	3.5	**20.0**	**Driven Monopile**
Nysted	Denmark	2003	Bonus	72	2.3	165.6	69	82	10	**5.0 -9.5**	**Gravity-Concrete caisson**
Arklow Bank Phase I	Ireland	2003	GE Wind	7 (200)	3.6	25.2	43	37	10	**2.0 - 5.0**	**Driven Monopile**
North Hoyle	UK	2003	Vestas V80	30	2	60	70	80	6	**10.0 - 20.0**	**Driven Monopile**
Scroby Sands	UK	2004	Vestas V80	30	2	60	70	80	2.3	**4.0 - 8.0**	**Driven Monopile**
Kentish Flat	UK	2005	Vestas V90	30	3	90	80	90	8.5	**5**	**Monopile**
Barrow	UK	2006	Vestas V90	30	3	90	80	90	7	**21.0 - 23.0**	**Monopile**
Egmond aan Zee (NSW)	Netherlands	2006	Vestas V90	36	3	108	80	90	10	**19.0 - 22.0**	**Monopile**
Burbo Bank	UK	2007	Siemens	25	3.6	90	80	106	6.4	**1.0 - 8.0**	**Monopile**
Lillgrund	Sweden	2007	Siemens	48	2.3	110.4	70	93	7	**4.0 - 8.0**	**Gravity-Concrete caisson**
Q7 -WP	Netherlands	2008	Vestas V80	60	2	120	58.4	80	23	**20.0 - 25.0**	**Monopile**
Horns Rev 2	Denmark	2008	Siemens	91	2.3	209.3	68	93	30	**9.0 - 17.0**	**Monopile**

Table 2.1 Wind farms currently operating

2.1.3. FOUNDATION DESIGN AND SIZING

2.1.3.1. Introduction to the foundations design

Once the type of foundation is selected, it is necessary to know some features in order to design the monopile. The diameter and wall thickness of the cylinder has to be calculated according to the natural frequency of the OWEC and the main frequencies (1P and 3P) at operating conditions as well as to withstand the loads derived from waves and currents. The transition piece has to be also designed in relation to the main sea level because of the boat landing platform.

Given the access granted to FINO 1 database, the most significant parameters will be calculated from the original real data.

2.1.3.2. Sizing the monopile

As a detailed structural analysis of the foundations is not the purpose of the project, some simplifications will be made to ease the calculation of the main features of the pile.

The importance of proper modeling the structural dynamics can be most conveniently illustrated by considering a single degree of freedom mass-spring-damper system. A complete offshore wind turbine system can be thought of as being constructed of a number of coupled multi degree-of-freedom mass-spring-damper systems.

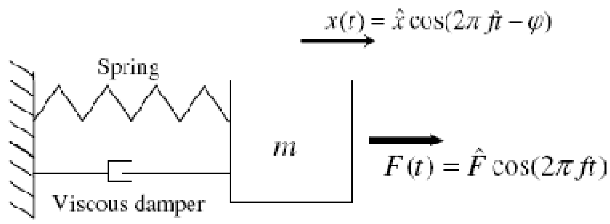

Figure 2.22 Single degree of freedom mass-spring-damper system

When a harmonic excitation F(t) is applied to the mass, the magnitude and phase of the resulting displacement x strongly depend on the frequency of excitation f. Three steady state response regions can be distinguished:

a) Quasi-static
b) Resonance
c) Inertia dominated

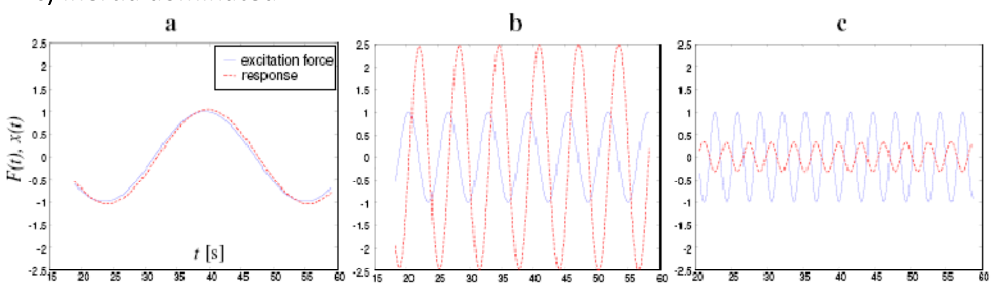

Figure 2.23 a) Quasi-static b) resonant and c) inertia dominated response
Solid blue line: excitation, dashed red line: displacement

For frequencies of excitation well below the natural frequency of the system, the response is quasi-static: the displacement of the mass follows the time varying force almost instantaneously, as if it was excited by a static load.
Figure 2.23 b) shows a typical response for frequencies of excitation within a narrow region around the system's natural frequency. In this region the spring force and the inertia force (almost) cancel, producing a response that is a number of times larger than it would be statically. The resulting amplitude is governed by the damping present in the system.

For frequencies of excitation well above the natural frequency, the mass cannot "follow" the excitation any more. Consequently, the response level is low and almost in counter-phase, as illustrated in Figure 2.23 c). In this case the inertia of the system dominates the response.

To translate the basic model of the previous mentioned to a wind turbine system, first the excitation frequencies are examined first. The most visible source of excitation in a wind turbine system is the rotor. As shown in section 2.6.5, the rotor samples the turbulent eddies in the wind field creating peaks in excitation at frequencies of 1P and 3P for a three bladed rotor.

Excitation
These two frequencies are plotted in a graph as shown in Figure 2.24. The horizontal axis represents the frequency [Hz] and the vertical axis represents an arbitrary response without values. Though higher order excitations do occur, here only 1P and 3P are considered as these are the primary excitations. To avoid resonance, the structure should be designed such that its first natural frequency does not coincide with either 1P or 3P excitation. This leaves three possible intervals. A very stiff structure, with its first natural frequency above 3P is called a stiff-stiff structure; if the first natural frequency falls between 1P and 3P, the structure is said to be soft-stiff while a very soft structure with its first natural frequency below 1P is called a soft-soft structure.

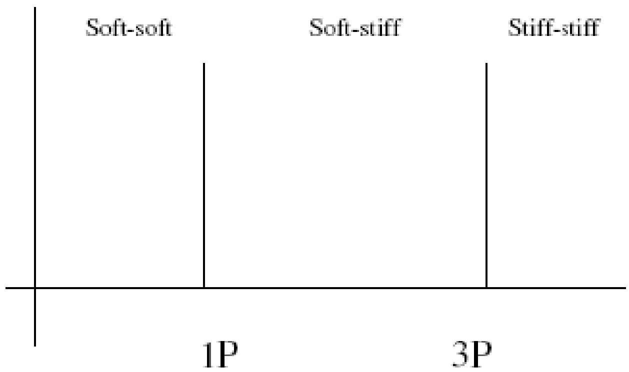

Figure 2.24 Soft to stiff frequency intervals of a three bladed, constant rotational speed wind

The support structure

A flexible wind turbine can be modeled as a flagpole with top mass m_{top}, as depicted in Figure 2.25. This model resembles the model of the mass-spring-damper system in Figure 2.22. The bending flexibility of the tower represents the spring stiffness; the damping is given in the form of a damping coefficient.

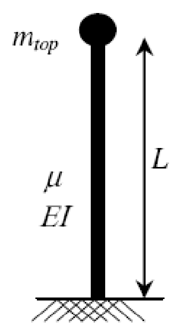

Figure 2.25 Structural model of a flexible wind turbine system

For this model consisting of a uniform beam with a top mass and a fixed base, the following approximation for the calculation of the first natural frequency is valid[16]:

$$f_{nat}^2 \cong \frac{3.04}{4\pi^2} \frac{EI}{(m_{top} + 0.227\mu L)L^3}$$

where:

f_{nat}	first natural frequency	[Hz]
m_{top}	top mass	[kg]
μ	tower mass per meter	[kg/m]
L	tower height	[m]
EI	tower bending stiffness	[Nm^2]

And using the following parameters:

$$I \cong \frac{1}{8}\pi D_{av}{}^3 t_w \text{ and } \mu = \rho_{steel}\pi D_{av} t_w \text{ and } a = \frac{m_{top}}{\rho_{steel}\pi D_{av} t_w L}$$

The equation above can be re-written as:

$$f_{nat} \cong \frac{D_{av}}{L^2}\sqrt{\frac{E}{104(a+0.227)\rho_{steel}}}$$

with:

t_w	tower wall thickness	[m]
D_{av}	tower average diameter = $D - t_w$	[m]
ρ_{steel}	density of steel (7850)	[kg/m^3]

As the cost of procurement and handling of large tubular towers is mainly influenced by the diameter, from an investment point of view the selection of the "softest" structure will be the best.

As variable speed turbines are gaining market share from constant speed turbines, in this project variable speed turbines were considered only. They offer higher energy capture and lower dynamic excitation. These turbines have a rotational speed range (e.g. Siemens SWT-3.6-107 range between 5 and 13 rpm). This means that the interval for a soft-stiff design is correspondingly narrower, as shown in Figure 2.26.

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[16] **Vugts, JH** (2000) *Considerations on the dynamics of support structures for an OWEC* Section Offshore Technology, Delft University of Technology

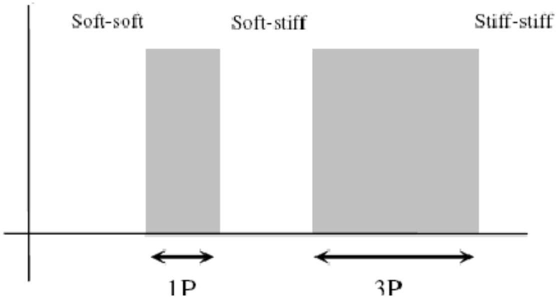

Fig. 2.26 Frequency intervals for a variable speed turbine system

Besides, the trend to create larger turbines is strong. This means that rotor blades become longer and tower top masses (generator) larger. The increase in rotor diameter has a direct effect on the soft to stiff approach.

The power performance of a turbine can be represented as a function of tip speed ratio. The tip speed ratio can be expressed as:

$$\lambda = \frac{V_{tip}}{V_w} = \frac{\Omega R}{V_w} = \frac{f_{1P}\pi D_{rotor}}{V_w}$$

The corresponding 1P rotational frequency is given by:

$$f_{1P} = \frac{\lambda V_w}{\pi D_{rotor}}$$

This means that for a fixed (optimal) tip speed ratio the rotational frequency will decrease when the diameter increases. The results of the equation above for a wind speed of Vw = 11.4 m/s, λ= 8 and rotor diameters of 80 m, 100 m and 120 m, respectively, are plotted in Figure 2.27.

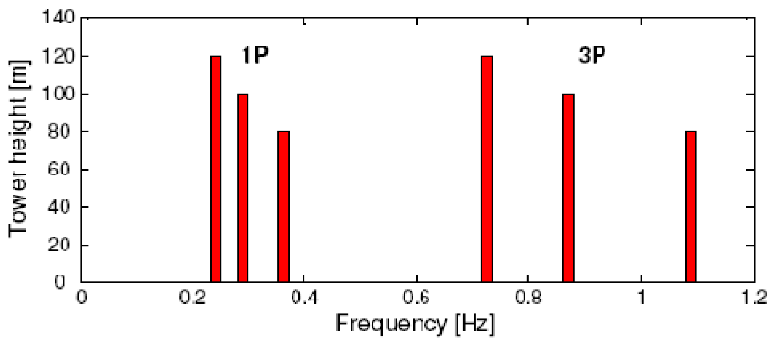

Fig. 2.27 1P and 3P frequencies for 80, 100 and 120 m diameter rotors

The increase in rotor diameter also requires a higher hub height. The natural frequency is seen to be inversely proportional to the tower height L squared. This means a large decrease of natural frequency with increasing height.

The design aim would be to create a soft-soft support structure, because it uses less steel and is therefore more cost-effective. The trend for the natural frequency of the support structure indeed seems to be moving to this soft range when applying larger rotors and structures and variable speed turbine, with a major risk of resonant behaviour due to wave excitation. In this connection there are two important phenomena that play a role: aerodynamic damping and controllability of variable speed turbines.

Aerodynamic damping

It is known that when a typical soft-soft support structure is designed to prevent resonant excitation by the 1P frequency of the rotor, it would encounter waves with frequencies near its natural frequency for some 10% of the time (see Figure 2.28). Although resonant behaviour will occur, the dynamic response is significantly reduced as the wind loading on the rotor adds damping to the system, which considerably reduces the height of the response peak. The tower top displacement and the total fatigue damage are thus correspondingly reduced. However, this aerodynamic damping is not present when the turbine does not produce energy (i.e. when blades are idling or parked). It has been calculated in some studies that when compared to a parked turbine, the fatigue life of most OWECs support structure will be doubled when the turbine is in operation.

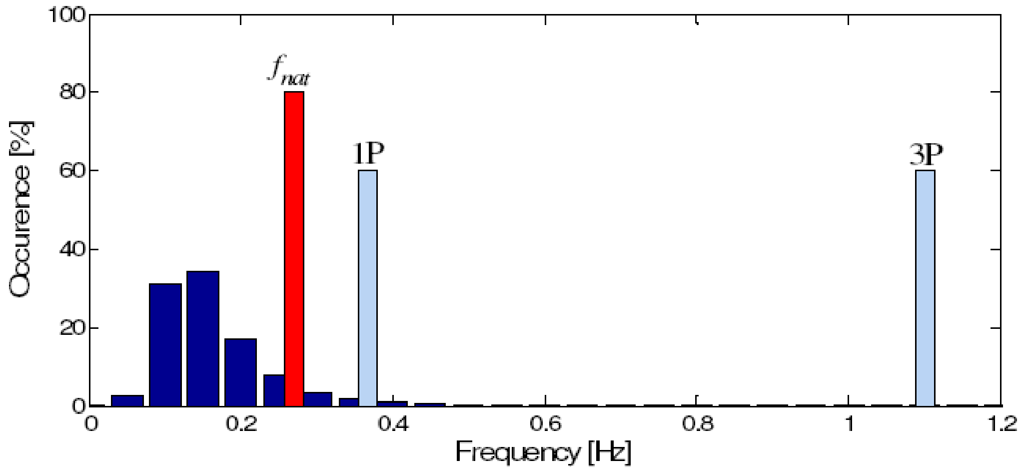

Figure 2.28 Occurrence of wave frequencies with plotted 1P and 3P frequencies for properties of a 3 bladed turbine off the North Sea

Variable speed turbines

Variable speed turbines are equipped with sophisticated controls to keep the system running at optimum speed. Although the variability of the rotation speed narrows the intervals of "safe" natural frequencies for the support structure (see Figure 2.26), the controller can be used to create new intervals. Even though the natural frequency lies in the range of the rotational frequency band, the controller can be programmed to skip rotational frequencies around the natural frequency. This will prevent the rotor from exciting the tower's natural frequency. The tuning of the controller can best be done after installation and measurement of the actual first natural frequency of the support structure, because uncertainties in soil conditions and installation particularities can cause the actual natural frequency to deviate appreciably from the design.[17] As an example, this frequency skipping by the control system has been applied successfully at the Utgrunden Wind Farm in Sweden.[18]

Sizing of the selected support model at project conditions

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[17] **Zaaijer, MB** (2000) *Sensitivity analysis for foundations of offshore wind turbines*, Section Wind Energy, WE 02181, Delft

[18]**Kühn, M** (2001) *Dynamics and Design Optimisation of Offshore Wind Energy Conversion Systems* Institute for Wind Energy, Delft University of Technology ISBN 90-76468-07-9

The turbine model selected to be installed for this project is the Siemens SWT-3.6-107, which has a mass top of approx. 220,000 kg (nacelle: 125 t; rotor: 95 t) and about 105 meters tower height (25 meters under sea level and 80 meters above sea level).

Approaching the design to a soft-soft structure and applying the formulae previously seen, an approximate sizing of the support structure will be made.

Applying these values to the equation of the natural frequency, assuming the values in Figure 33 for a 100 meters rotor diameter and tower height (o.3 Hz for 1P) and giving an estimated value for wall thickness of 0.1 meters, the resulting diameter of the pile is 3.15 meters**.**

If the design approach goes towards a stiffer structure in order to avoid low frequencies due to the increasing rotor diameter and hub height (which leads to lower rotational speeds of the rotor) and also avoid sea conditions with wave frequencies near the natural frequency of the OWEC, then other values have to be applied in the equation.

Going further the 3P frequency value to achieve a stiff-stiff structure, some data have to be changed in order to get the pile diameter. The natural frequency now is about 0.9 Hz, and since a larger diameter is expected, the wall thickness will be slightly higher as well. The rest of the features will remain the same. Applying these other values then the resulting diameter is 7.41 meters.

These calculations are mere approximations, made in order to know the size range of the support structure, since an actual offshore wind turbine support structure will be dimensioned for many more influences. For instance, the soil properties will always be more flexible than the assumed fixed connection of the model in Figure 2.25. This flexibility will result in a lower overall natural frequency, which may need to be compensated by increasing the diameter.

Another part to design is the transition piece. It is the connection between the monopile driven into the soil and the regular turbine tower. Although both parts are tailor made for every single site according to the parameters seen previously such as water depth, seabed features and wind conditions in order to gather the most wind power possible, a transition piece is needed to fit both parts as well as to ease the access to each OWEC.

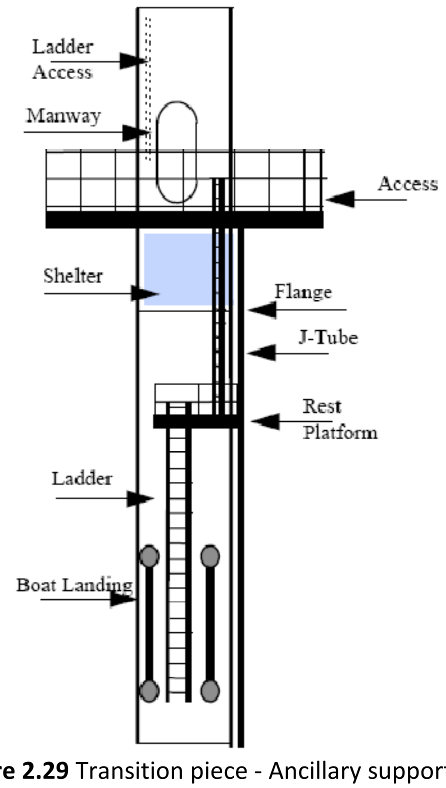

Figure 2.29 Transition piece - Ancillary support system

The common parts in every transition piece installed in monopile foundations are listed in the figure on the right.

In this particular case considering the reference water depth of 25 meters, and the tidal range between 1 and 2 meters, and being the significative wave height range (according to the FINO platform data) from 1 to 2.5 meters, the boat landing facility should be about 27 and 30 meters above seabed level.

2.2. Installation

2.2.1. MONOPILE INSTALLATION METHODOLOGY

The installation of offshore monopiles would be carried out from a jackup barge, which furnishes a stable platform from which construction work can take place. For the activity of installing monopiles the jackup would normally be equipped with pile gates capable of holding and guiding the pile during the installation process and releasing it afterwards. In order to get the pile into the ground a hole will typically be pre-drilled. The method by which this is done varies. For a typical case the system is as shown in Figure 2.30.

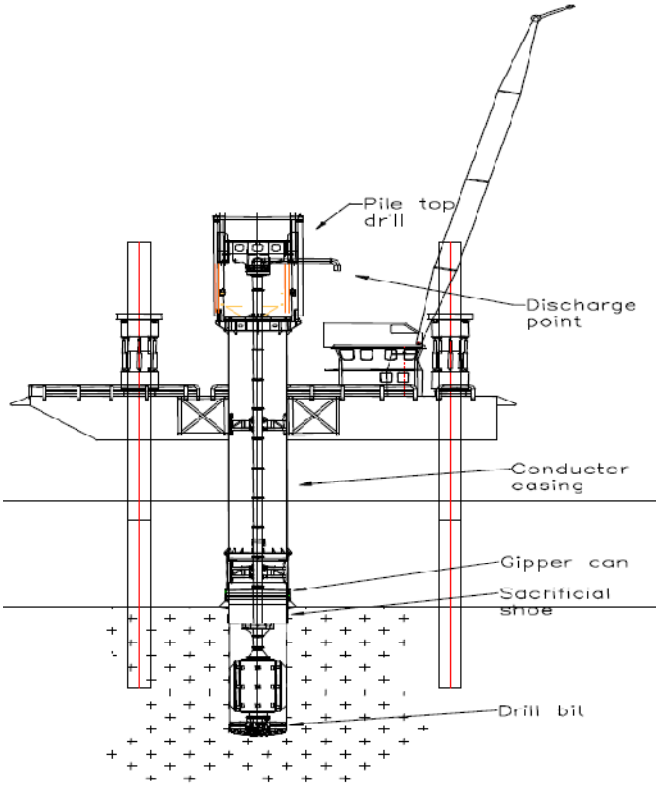

Figure 2.30 Typical offshore driving method

Although flexible in terms of ground conditions, large diameter drilling has slow penetration rates in comparison to driving and also involves multiple operations in deploying the conductor and pile top drill prior to placement of the pile. Subsequently the placed pile must be surveyed for verticality and then grouted into position; there is then a further delay while the grout is allowed to cure. Here the conductor or guide casing serves to support the upper part of the hole in the soft unstable material or overburden. In addition the conductor supports the drill and is employed to align and position the hole.

Only after that can temporary support be removed and turbine erection started. This method is not efficient in dealing with substantial overburden thicknesses (in the project's site about 1 meter) and can result in an equal amount of time spent casing the hole as is spent drilling. The efficiency on the airlift system regulates the drilling rates, and this is partly governed by the height of conductor used. To overcome the above limitations of the airlift requires increasing the capacity and heavy investment in compressors.

A study made at the University of Bristol can give some guidance regarding the selection of the methodology used to install the foundation. Some of the most useful which will be going to be considered are:

- ✓ Increasing turbine generating capacity has forced the use of increasing diameter (soon to exceed 10m) monopiles. Hammers will no longer be economically viable for insertion.
- ✓ Piles installed by jetting have much lower lateral static resistance than piles installed by driving.
- ✓ Piles installed by driving in calcareous sands have stiffer p-y curves and therefore larger lateral capacity than piles installed by jacking.
- ✓ Drilling pilot holes ahead of the pile may aid driving but may soften the soil adjacent to the pile and lead to reduced lateral capacity.
- ✓ Given that monopiles for wind farms typically have length to diameter ratios less than about 8 (which is smaller than that required to allow plugging), the API (1993) recommendation is that piles should only be installed by methods other than driving as a last resort. If a requirement of zero toe movement is to be enforced, then jetting is a particularly undesirable installation technique.
- ✓ The p-y method is the best available design tool for laterally loaded monopiles with embedded length to diameter ratios larger than 4.5, wall thickness to diameter ratios larger than 0.02 and diameters as large as 8m. Use should be made of the p-y curves published in the literature, not just those appearing in the API (American Petroleum Institute) and DNV (Det Norske Veritas) guidelines.
- ✓ Driving appears to be the optimal installation method for piles in soils and chalk (using current pile diameters).

Although some other techniques are becoming a real option as the pile diameter increases and current methods will be uneconomic, and as a conclusion of this study and following the API Guidelines that recommend hammer driving as the preferred method of installing the present generation of monopile foundations, the methodology which will be used for the pile installation is the hammer driving method.

2.2.4. LOGISTICS OF THE INSTALLATION

Once the type of foundation and the installation methodology are known, all the logistic aspects have to be defined in order to plan the equipments needed and the detailed schedule of operation.

First of all the base seaport has to be selected. It has to meet all the requirements to host the equipment (barges, cranes, etc…) and it also has to be properly furnished with the necessary tools and space to carry out the pre-assembly of some of the parts of the OWEC when needed.

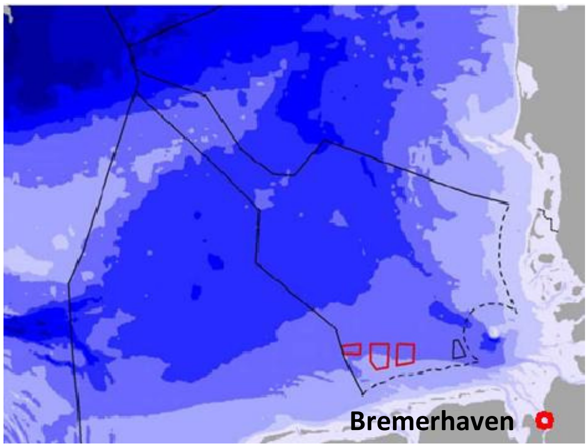

Figure 2.31 Bremerhaven port location

Not far from the wind farm site a seaport which meets all the conditions already exists. It is the Bemerhaven seaport, which is already thought to host all the facilities related to offshore wind farms and their installation.
Up to now this harbor is provided with all the facilities needed to carry out there the pre-assembly and to settle the transport infrastructure. Within those facilities are heavy load quay-side, a 32 meter lock on the River Weser, a wind energy joint heavy load terminal (“Luneort”), a motorway close to the harbor, railway access to the harbor, and many companies

manufacturing blades, towers, foundations, turbines and other OWEC parts. Besides there are a number of R&D centers also.

2.2.2.1. Weather Windows

Weather conditions are one of the most important constraints to consider when analyzing the installation methodology and procedure. The equipment to be used during the installation of both the foundation and the turbine itself are very dependent on weather conditions, mainly sea surface state. The key parameters that influence the optimum operation of the barges and vessels involve are the wave height and the wave period. The following chart shows the relation between the type of equipment and these two parameters.

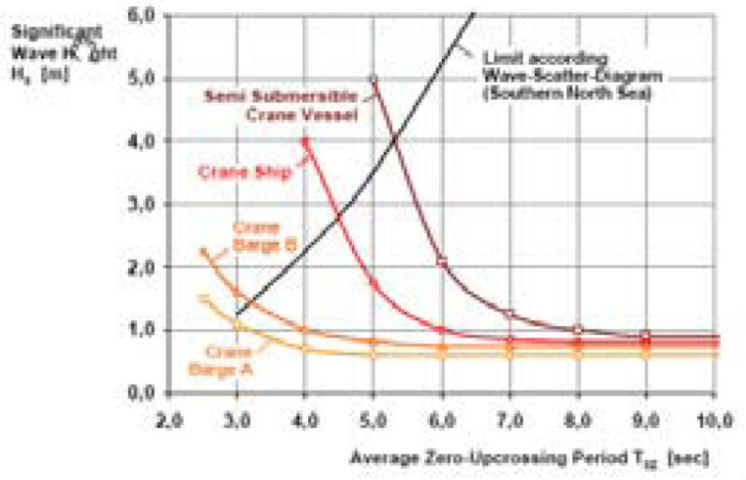

Figure 2.32 Operation feasibility depending on wave height and period

As it will be shown later, the optimal equipment to carry out the installation of the wind farm necessitate strict conditions to operate properly and safely. As a general rule for the type of barge and crane vessels considered to be used the desirable operation conditions are less than 1 meter of significant wave height and an average wave period up to 4 seconds.

Using the data gathered from the FINO1 platform, an analysis of these two parameters has been done.

Regarding the significant wave height, the monthly average values and data availability are shown in the following table.

The analysis points out that there are a period between April and August when the conditions are met during long periods of time. The average significant wave height value of these months is close to 1 meter and there are several periods when the value is less than 1 meter.

During these months, and considering the analyzed real data, it is expected to have at least 80 days where the conditions would allow the operations. Considering that this is an expected minimum value, and assuming an average of two days per turbine installation, it is fair to say that all the wind farm installation could be accomplished in one season.

The second table shows the same data analysis for the average wave period. It has been found out that this parameter will not add any time constraint because the operational value is always achieved during the optimal weather windows defined by the wave height.

SIGNIFICANT WAVE HEIGTH AT FINO 1 PLATFORM

2007	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	Average
Hs	**3.00**	**1.39**	**0.86**	**1.12**	**1.19**	**0.97**	**1.39**	**1.28**	**2.10**	**0.85**	**2.22**	**1.72**	**1.51**
% availability	94.2%	71.0%	16.3%	90.0%	82.9%	98.5%	96.5%	91.7%	91.5%	8.6%	47.6%	100%	74.1%
2006	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	Average
Hs	**1.32**	**1.77**	**-**	**0.72**	**1.18**	**0.96**	**0.59**	**1.22**	**1.14**	**1.67**	**2.93**	**2.00**	**1.41**
% availability	92.7%	16.6%	0.0%	32.4%	99.9%	99.9%	84.6%	73.1%	99.9%	99.9%	51.5%	47%	66.4%
2005	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	Average
Hs	**2.58**	**1.94**	**1.34**	**1.03**	**1.12**	**1.04**	**1.07**	**1.30**	**0.87**	**1.21**	**1.74**	**1.96**	**1.43**
% availability	47.2%	96.3%	54.8%	99.9%	100.0%	99.7%	100.0%	99.6%	30.2%	100.0%	100.0%	100%	85.6%
2004	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	Average
Hs	**1.66**	**1.81**	**1.60**	**1.30**	**1.12**	**1.34**	**-**	**1.33**	**1.16**	**1.09**	**0.61**	**1.79**	**1.35**
% availability	89.6%	65.4%	19.2%	43.7%	94.1%	87.0%	0.0%	84.4%	38.8%	0.1%	0.3%	48%	47.5%
													Average
Average	2.14	1.73	0.95	1.04	1.15	1.08	0.76	1.28	1.32	1.20	1.88	1.87	**1.37**
Avg. >60%	1.99	1.71	0	1.07	1.15	1.08	1.02	1.28	1.62	1.44	1.74	1.84	**1.33**
Rep. Year	**1.66**	**1.81**	**1.34**	**1.03**	**1.12**	**1.04**	**1.07**	**1.28**	**1.14**	**1.21**	**1.74**	**1.96**	**1.37**

Table 2.2 Average significant wave height at FINO1 Platform

AVERAGE WAVE TIME PERIOD AT FINO1 PLATFORM

2007	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	Average	Avg. >60%
Ts	**6.35**	**4.71**	**3.76**	**4.82**	**4.66**	**4.31**	**4.66**	**4.70**	**5.67**	**4.39**	**5.59**	**5.51**	4.93	5.04
%availability	94.2%	71.0%	16.3%	90.0%	82.9%	97.3%	96.5%	91.7%	91.5%	8.6%	47.6%	100%	74.0%	90.6%
2006	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER		
Ts	**4.64**	**5.50**		**4.79**	**4.44**	**4.43**	**3.84**	**4.77**	**4.29**	**4.88**	**6.32**	**5.55**	4.86	4.47
%availability	92.7%	16.7%	0.0%	32.4%	99.9%	98.7%	84.5%	73.1%	99.9%	99.9%	51.5%	47%	66.4%	92.7%
2005	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER		
Ts	**6.41**	**5.58**	**4.89**	**4.76**	**5.03**	**4.61**	**4.64**	**5.00**	**4.21**	**4.61**	**5.57**	**5.47**	5.07	5.91
%availability	47.2%	96.3%	54.8%	99.8%	100.0%	98.3%	100.0%	99.6%	30.1%	100.0%	100.0%	100.0%	85.5%	99.3%
2004	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER		
Ts	**5.38**	**5.51**	**4.76**	**4.72**	**4.86**	**4.81**		**4.60**	**4.62**	**5.80**	**3.76**	**5.64**	4.95	5.03
%availability	89.4%	65.5%	19.2%	43.7%	94.0%	85.9%	0.0%	84.4%	38.8%	0.1%	0.3%	47.6%	47.4%	83.8%

	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	Average
Average	5.69	5.32	4.47	4.77	4.75	4.54	4.38	4.77	4.70	4.92	5.31	5.54	**4.93**
Avg. >60%	5.45	5.27		4.79	4.75	4.54	4.38	4.77	4.98	4.74	5.57	5.49	**4.98**
Repr. Year	**5.38**	**5.51**		**4.76**	**4.66**	**4.61**	**4.64**	**4.77**	**4.29**	**4.88**	**5.57**	**5.51**	**4.96**

Table 2.2 Average wave time period at FINO1 Platform

2.2.2.2. Operations

The pile handling operation consists of a number of separate tasks:

2.2.2.2.1. Pile delivery

This starts with the delivery of the pile to the worksite; although a supporting operation it must be sufficiently robust with regard to weather conditions. The task is usually carried out either by flotation and towing the pile to the worksite, or as deck cargo using a suitable vessel.

In the case of the barge transport the pile can be adequately protected and secured for the journey and there is no need for any sealing arrangement (bungs). A single vessel is required with good manoeuvrability and position control.

Figure. 2.33 Pile towing

Alternatively when dispatched by flotation there is no limit on the size of the vessel or lay down area. There are also inherent advantages for pile handling, the geometry for reorientation of the pile is far better and there is the option of a buoyant lift and ballasting of the pile. These options are essential when trying to keep the working heights to a minimum. The tow craft can also offer a supporting role during the critical initial lift.

In this particular case the pile will be bunged at both ends and floated and towed to the installation site.

2.2.2.2.2. Pile docking – Initial lift

Once on position at the site the pile must be captured by the lifting apparatus; the initial lift gives partial control of the pile to the installation rig but this remains a critical operation with limited control and maximum exposure to the wave forces.

Normally reorientation of the pile into the vertical is subject to the limitations of water depth and rig height against the pile length. This operation is usually sensitive for all water depths: shallow depth places restrictions on the use of buoyant lift technique and additional time constraints due to the tidal window; whereas deep water (as in this case) forces the jack up rig to work close to its height limit and increases its vulnerability to weather.

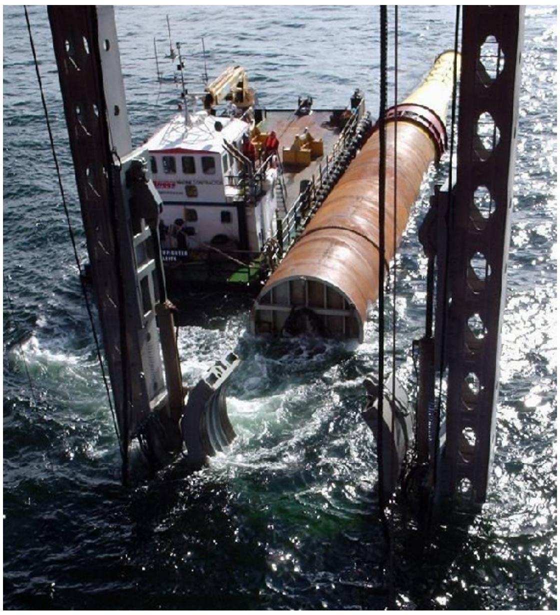

Figure 2.34 Pile approaching the gate

Conventional techniques include a dry lift or semi buoyant lift, this is obviously dependant on whether the pile is towed or carried by barge as discussed previously. A dry lift necessitates the jack up crane being able to take the full weight of the pile, this limits current vessels suitable for such a lift and will be a considerable handicap in the future when pile are predicted to top the 500 tonne level. It also has implications for the maximum working height of the crane. With this type of lift the crane is in sole control of the pile until it enters the pile gates. This results in a significant period of insecurity during the initial lift where there is negligible lateral restraint of the pile. These are some of the reasons why the selected delivery option is floating and towing the monopile.

On the other hand there are substantial gains to be had in the use of a semi buoyant lift. Typically the crane load can be reduced to less than 50% of the actual pile weight. Firstly a line is attached to the pile and position maintained in order to initiate the lift. During this operation the pile continues to pitch and roll under the prevailing sea state (the considerable length of the pile can make this a particular problem with the pile being pushed off position). Once the first end of the pile is out of the water the sensitivity decreases but further attention must be paid to the free end during the ensuing lift. This can be augmented by ballasting the pile to minimise turning heights.
The pile handling system can be customised to compensate for the aspect ratio of the pile and some of the vulnerabilities of its initial pickup. Part of the height restriction is the need to lift it from one end. The floating end of the pile is a considerable distance from the vessel crane, limiting any control possible from the vessel. It imposes the largest rotation radius on the pile, i.e. the full height of the pile must be achieved in order to reach the vertical position. This can be overcome by picking the piles up from an intermediate position e.g. centre of gravity. This not only reduces the minimum rotation height by half, but also the wave and current induced moments on the floating end.

2.2.2.2.3. Pile lift and reorientation

Historically pile lift and reorientation has involved the use of a crane with sufficient capacity and a set of pile gates. Here the pile is vertical before any lateral support can be gained from the gates, importantly there is no weight sharing with the crane. This means the lift is reliant on the serviceability of the crane for the full duration of the lift, with there being no backup system powerful enough to complete the operation if problems with the crane are encountered. Once in the vertical position there is little assistance the workboat can offer, and the pile is vulnerable to wind and wave action until it can be captured within the pile gates.

These points are equally true of a buoyant lift and further aggravated by the fact that the crane may not be capable of taking the full pile weight if there is an unscheduled loss of buoyancy. There is no direct control over pile orientation during pile lift, it can only be coaxed by judicious use of the crane / ballast and work boat to counter buoyancy and

Figure 2.35 Initial pile lift

environmental forces. Whilst a crane of sufficient capacity would overcome any immediate limitations – it does not reduce the period of risk during the lift and in the future it can be assumed that environmental forces will increase proportionally with the size of the pile. As in the case of docking and initial lift, a fully mechanised pile handling system would offer a far greater degree of security with less manual intervention and reduced susceptibility to environmental factors. It would be incorporated into the initial lift and be capable of elevating the pile centre to a suitable height to complete the reorientation, preferably maintaining full control of the pile attitude during the process. The multicat/work boat responsible for pile delivery may act as back up offering a correcting force if the pile toe drifts outside an acceptable tolerance. With the pile in the vertical position the lift system then acts as a manoeuvrable set of pile gates, allowing secure guidance of the pile to the sea bed. Conventionally the pile is picked up with the pile pointing away from the vessel. Early studies suggest that the pile length is prohibitive to using a central lift in this configuration as the size of the moonpool would not give enough clearance. Thus a reverse lift has been contemplated; here the pile is presented under the vessel and rotated in the opposite sense to usual.

Figure 2.36 Pile lift and reorientation

The monopile weight and size has already been established, these dimensions have been used in selecting the appropriate vessel. A jack up barge with heavy lift capability has been identified as the base for the pile handling system. It can work effectively in 25m of water and has a lift capacity of 280t at 50m above the deck. It was chosen in preference to a floating crane barge because of its greater flexibility in adapting to different operating heights and its stable foundation for deploying heavy plant, along with being able to stay on station in bad weather. In the case of both jack up barges and floating crane vessels their operating windows are severely compromised when considering lifts close to the cranes capacity.

There are not many barges which meet the requirements specified above. In the following table may be seen the number of each installation equipment currently available.

#	Type of Equipment used in the Offshore Wind Industry	Approx No of relevant Equipments in the Market
1	WTG Installation Vessels	4
2	Foundation Installation Vessels	6
3	Infield Cable Installation Equipment	3
4	Export Cable Installation Equipment	4
5	Hydraulic Hammers for Mono Piles	6
6	Drilling Equipment	3
7	Export Cable Carrousels	3
8	Crew Vessels (fast once)	10

Figure 2.37 Installation equipment currently available

Different barges were considered for this project. A number of companies such as Seacore, A2SEA, Vroon Offshore Services among others can provide this kind of vessels. Beyond the technical requirements it is at least as important as them the availability of these vessels. For some of them four-year waiting list exists which makes the schedule of the project conditional on their availability.

At this stage of the project it is impossible to determine which one of the vessels will carry out the installation of the monopiles due to the availability constraint. Although, some proposals are made to be taking into account such as the following barges: *Sea Jack* and *Sea Worker* from *A2SEA* and *Excalibur* from Seacore (with more than 40 meters water depth and good operation in adverse weather conditions).

Figure 2.38 Sea Worker and Excalibur jack up barges

2.2.2.2.4. Turbine installation

The turbine installation process will be carried out by means of crane vessels. A pre-assembly of the OWEC will be done at Bremerhaven port. Regarding to the tower, it will be fully assembled into one piece in order to be transported as a whole. On the other hand, a "bunny ears" set-up will be carried out assembling two of the blades to the rotor and itself to the nacelle. This way the third blade (the one pointing down) will remain to be installed only.

Figure 2.39 Towers and "bunny ears" nacelle set-up ready to delivery

To achieve the right installation of the turbines crane vessels will be used. Many requirements similar to those that came up when analyzing the monopile installation procedure will need to be fulfilled. The main issues here are the height of the crane to reach the top of the turbine as well as the operation under particular weather conditions as it could be seen before.

Equipment availability is again a key point in order to schedule the operations. Therefore a list of proposed vessels which meet the specifications to install the turbines will be named but not a single one will be chosen as the one to be used.

The proposed vessels are: Sea Energy and Sea Power from A2SEA and Rambiz from Scaldis-Salvage & Marine Contractors N.V. They meet the requirements of weather conditions and crane height among others.

Figure 2.40 Turbine installation

2.2.2.2.5. Offshore substation

In addition to the turbines, the offshore substation needs to be installed. Same soil and sea conditions as for the turbines installation apply. Therefore, the installation equipment will be the same as for the turbines.

2.2.2.3. Decommissioning

At the end of the project lifetime, if a repowering operation is not considered, the turbines and their foundations will be removed using the same type of equipment as to be installed, or that one considered more suitable when the operation would take place.

2.3. REFERENCES

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3. Electrical Collection, Transmission and Control System

CONTENTS

3.1. INTRODUCTION DOCUMENT

Now that suitable sites for additional wind farms onshore have become scarce in many European countries, the major efforts today are directed to develop future wind farms offshore.

Offshore wind farms are likely to be larger than those onshore as the economies of scale in offshore projects are more significant. Also, a considerable part of them will be located far away from shore. Therefore, with several very large offshore wind farms planned to be built off far away from the coast, new engineering challenges have risen. The design, construction and operation of large scale power plants, positioned far out at sea in hostile environments, require significant skills in the design and construction. The development of these projects raises new issues in the electrical connection to the electricity grid and need to be optimized case by case.

3.1.1. Offshore vs. Onshore Wind Farms

Offshore wind farms are different from those onshore in many aspects; this fact implies that a new way of thinking about the electrical aspects is required. From the point of view of connection to the grid, offshore wind farms have specific characteristics with regard to onshore wind farms:

- More powerful wind turbines, to compensate for the greater costs of foundation.
- Greater length of the electric lines in the wind farm, due to the greater separation between wind turbines.
- Greater distances to the connection to the grid.
- Longer times to repair faults.
- Less frequent schedules maintenance.
- More aggressive environment.
- Less space available for equipment.
- Possibly a regular array with more freedom to choose cable routes.
- New connection systems to the grid (alternating current AC or direct DC).
- New problematic with regard to the fulfillment of the new requirements for the transmission in AC or DC and the connection to the grid.

This casuistic involves that main design criteria for the electric transmission system in offshore wind farm are:

- Equipments must be the most compact as possible, with great intervals for the maintenance or even design for not having maintenance.
- High reliability of operation and in critical zones redundancy must be included.
- Installations must be resistant to corrosion caused by the air of the sea, which is highly humid and contains salt, so equipments placed inside or even hermetically closed paces must be used.

3.1.2. Requirements related to Networks Connection

All national grids discuss the importance of grid support from all installed power generating devices. Many regulatory authorities require that the generators should be able to vary their reactive power output dependent on the grid voltage level. This requirement is a result of the desire to maintain voltage stability and limit dynamic voltage variations. Wind farms have been often excluded from these demands as they typically have had a small power rating. In the past, in the event of faults wind farms were disconnected immediately from the grid. Now, with wind farms growing into the range of big or medium sized power plants, wind farm connections must be designed so that the wind turbines are capable of continuous uninterrupted operation.

The most recent grid codes, including the German one, require the wind farm, among other things, to contribute to:

- Reactive power exchange and voltage control
- Fault-ride through support in the case of balanced faults

and sometimes:

- Defined behavior in the case of unbalanced faults

Fault ride through requirements for different regulations can be seen in the following figure:

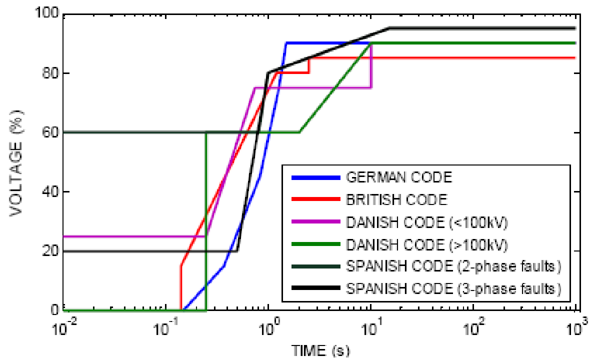


Figure 3.1. Ride through requirements for international regulations

These requirements are being taken into account along the project when making decisions on elements and configurations.

3.1.3. European and German Regulation

The Infrastructure Planning Acceleration Act, passed by the Budesrat at the end of 2006, alters the responsibility for financing and operating connection to the grid. Grid operators are now obligated to ensure grid connection for offshore wind farms situated further than 3 nautical miles (5.556 km) from shore and which construction begins before the end of 2015. The cost of grid connection will be carried by the network operator and can also be distributed across all transmission network operators.

This law looks for a new system approach that can reduce considerably costs due to synergetic effects. Instead of laying each cable separately to shore, cables are laid from an offshore wind park substation, which collects the power produced by all wind turbines, to an offshore node. This can be connected to several wind parks, and is also connected to the grid connection point on land via a high-voltage submarine cable. Offshore nodes can also be connected to one other, building an electrical integrated system for offshore wind farms, reducing costs and environmental impacts.

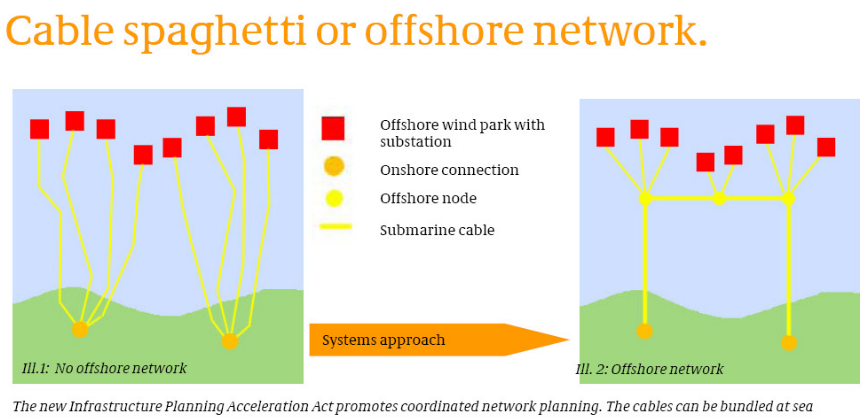


Figure 3.2. The old and new system approach

The Renewable Energy Directive, agreed in December 2008, establishes coverage of renewable energy of 20% of the total primary energy for the year 2020 and the European Commission has suggested that 12% of the EU electricity demand needs to come from wind to meet this target.

The following objectives have been previewed for Germany to meet this context: 25.000 MW offshore wind power until 2030, by contributing a 15% of the total.

It has been published that E.On Netz will build the first connection of direct current that will let to connect several offshore wind farms to shore: Alpha Ventus (1040 MW), Bard Offshore I (400 MW), Hochsee Windpark Nordsee (400 MW) and Global Tech I (360 MW). However, along the search of information for this report, no evidence has been found about the current existence or project approval of any submarine cable for turbines interconnection; it means it was not possible to find any information about any submarine cable electrical parameters, length, connection points, et cetera. Therefore, the connection of one farm has been just considered instead of considering an electrical integrated system for several offshore wind farms. Consequently, as it is deeply explained further, High Voltage Alternative Current (HVAC), instead of High Voltage Direct Current (HVDC) is the suitable option for transmission to shore.

3.2. ELECTRICAL SYSTEM OVERVIEW

The electrical system for an offshore wind farms comprises two parts: a medium-voltage electrical collection grid within the wind farm and a high-voltage electrical system to deliver the power to an onshore transmission line.

3.2.1. First Considerations

The first dilemma faced regarding electrical issues was the incorporation of an offshore substation to increase the voltage level and decrease transmission cost:

- No offshore substation: the offshore array is split into several sub-arrays, each connected to shore by its own cable. The size of each sub-array is determined primarily by the rating of the largest feasible MW submarine cable. No additional equipment offshore is required, each shore cable is protected by switchgear at the shore end and a transformer station steps up to the network voltage.
- Offshore substation: it will require a support structure, transformer and switchgear. Each substation may, or may not, have several sub-arrays connected to it. Design and maintenance of high-voltage offshore equipment involve new technical challenges.

For relatively small generating capacity wind farms it has been sufficient to bring the power to shore at the same voltage used to interconnect the wind turbine generators (typically 33 kV). But, as the energy generating capacity of the wind farm increases, the cost of submarine cables increases prohibitively combined with the excessive voltage drop. The use of an offshore substation makes possible to step up the medium voltage to high voltage suitable for transmission to shore. Some previous examples are: Nysted in Denmark, Lillgrund in Sweden and Q7 in the Netherlands. Taking into account the power of the wind farm that it is being designed, an offshore substation may be included. Moreover, this decision follow the philosophy of the German Regulation previously exposed.

Secondly, as it was mentioned before, the current German Regulation makes the grid operator responsible for the transmission system; therefore its detailed design is not included in the scope of this project as it is not a promoter's responsibility. Nevertheless, the alternatives for connecting offshore wind farms to the main grid will be briefly studied for academic purposes.

3.2.2. Collection System

The collection grid begins with transformers at each wind turbine, usually inside the tower, to step up from the generation voltage (typically 690 V in current offshore turbines) to a medium voltage (typically 25 – 40 kV) in order to reduce power transmission cost due to Ohmic resistance.

A grid of medium-voltage submarine cables, typically buried 1 or 2 meters deep in the seabed, is used to connect the wind turbines to an offshore substation; which function is to increase the voltage level to high voltage (typically 130 – 150 kV). This higher voltage allows a much smaller diameter and lower cost submarine cables to be used for the long distance to shore.

3.2.3. Transmission System

The transmission system begins from the offshore substation; a high-voltage submarine cable (which is also buried in the seabed for protection) carries the power to an onshore substation for connection to a transmission line. An additional transformer may be used in this substation to step up the voltage to a higher level to match the transmission grid, which is 380 kV.

3.2.4. Diagram

The following diagram shows a scheme of the collection and transmission system that has been just described:

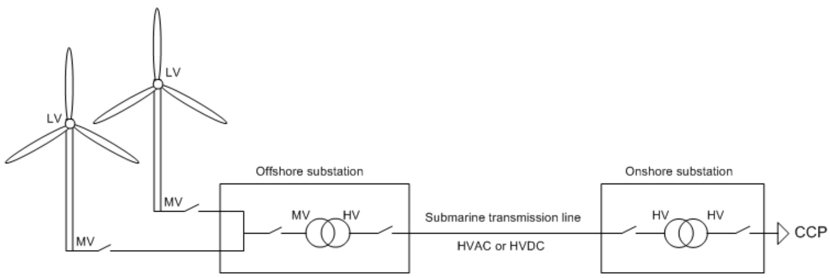


Figure 3.3. Collection and Transmission system for an offshore wind farm

3.3. ELECTRICAL COMPONENTS

3.3.1. Previous Considerations

Even though different technologies for the transmission system will be deeply developed in the next section, a brief introduction is now required. HVAC systems are used for transporting energy from wind farms with the same characteristics as the one being designed. However, for larger wind farms and/or longer distances, HVDC is more suitable; in this sense, this technology will be applied in the German roadmap of future wind farms interconnection. As it was mentioned before, no specific data was found about any HVDC cable electrical parameters. Therefore, the electrical design will be defined considering HVAC transmission system instead of HVDC, although some differences will be done.

3.3.2. Wind Turbine

The most common wind power generator is based on the asynchronous machine, since it is robust and cost effective. Induction generators, however, do not contribute to grid voltage regulation, and they are substantial absorbers of reactive power.

Generating AC at variable frequency with indirect grid connection offers some advantages. The frequency of the stators is varied with an inverter and thus the turbine can run at variable rotation speed. The generated AC current with variable frequency is first converted into DC with 50 Hz using an inverter or thyristors. The rectangular shaped waves finally need to be smoothed out with AC filters.

Variable speed generators are more efficient and capture more wind energy by operating most of the time close to the rated power of the turbine although some energy gets lost in the AC-DC-AC conversion process.

The wind turbine that has been previously selected for this project is SWT-3.6-107 (Siemens Wind Turbine, 3.6 MW, 107 m of diameter); an asynchronous machine with variable speed which main characteristics are summarized in the following table:

Generator

Type	Asynchronous
Nominal power	3,600 kW
Synchronous speed	1,500 rpm
Voltage	690 V
Frequency	Variable
Protection	IP54
Cooling	Integrated heat exchanger
Insulation class	F
Generator designation	AMB 506L4A

Table 3.1. Siemens generator technical specifications

Siemens wind turbines are provided with a power conversion system named NetConverter which allows generator operation at variable speed, frequency and voltage while supplying power at constant frequency and voltage to the MV transformer.

The NetConverter system is made up of an AC/DC converter, a DC bus and a DC/AC inverter which supplies the grid frequency. The DC bus decouples the output of the asynchronous generator from the grid. This system provides maximum flexibility in the turbine response to voltage and frequency requirements and fault conditions and can be adapted to meet the requirements of relevant grid codes, like the German one.

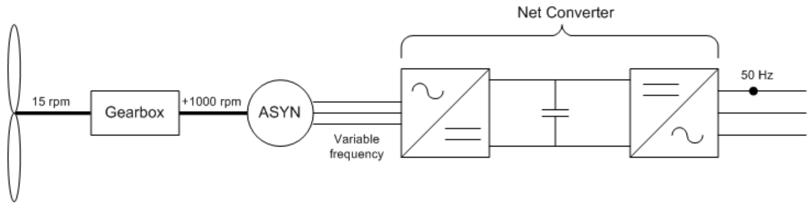


Figure 3.4. Siemens electrical wind turbine scheme

Switchgear is a combination of breaking devices, like circuit-breakers for short circuit current, load-breakers for rated current, disconnectors and fuses. Siemens wind turbines are provided with switchgear and protection devices as part of the controller system. Siemens switchgear is gas-insulated and can be readily accommodated in the tower of a wind turbine and operate at a voltage of 36 kV.

3.3.3. Low Voltage- Medium Voltage Transformer

Before leaving the tower, a transformer steps up the voltage produced by the generator from 690 V to 30 kV, a more conventional voltage level for transmission.

Different possibilities of location and technologies are discussed in this section.

3.3.3.1. Placement of transformer for each wind turbine

The placement of the transformer influences the design work on the wind turbine and support structure. Four options can be considered: inside the tower, on the access platform, at the main collection point and inside the nacelle. In any case, the location should guarantee that the transformer is placed at an absolute dry place and behind some partition-wall only accessible by special trained operators.

- **Inside the tower**

  The transformer can be pre-installed on land inside the tower segment which is installed on the foundation pile by means of grouting. It is also possible, but less usual, to place the transformer in the tower above the flange.

  The advantage forms the low cost involved compared to the other options, but, as drawback, a transformer placed inside the tower is more difficult to replace.

- **On the access platform**

  Placing the transformer onto an access platform has the advantage of easy installation and replacement. However, the cost involved in making the access platform suitable to bear the large weight is very high.

- **Transformer at the main collection point only**

  This option has been ruled out as it does not match with an offshore substation option.

- **Inside the nacelle:**

  The advantage to place the transformer inside the nacelle is that it can be tested, in combination with the generator of the wind farm, at the assembly hall.

After evaluation all the options, the nacelle and tower locations seem to be more feasible. Although the nacelle seems to be the most economic location, the transformer will be finally installed inside the tower, where more space is available.

3.3.3.2. Transformer choices

Formerly, dry-type transformers were installed in the vast majority of wind turbines because of their good fire behavior and compact dimensions. However, liquid-filled transformers, with fire-retardant fluid, have been developed for the multi-megawatt turbines because their performance and reliability makes them particularly suitable to such applications.

The main difference between the liquid-filled and dry-type transformer technologies is the electrical insulation medium, paper/liquid and air/resin insulation respectively. The conventional liquid-immersed transformer uses cellulose and mineral oil, whereas an advance in this technology uses a high temperature aramid insulation material called NOMEX (a variant of Kevlar) and silicone liquid or a biodegradable ester liquid respectively. The insulation structure also contributes to heat management and mechanical integrity. Mineral oil, as used in conventional transformers, has been replaced by silicone or ester liquid, because the latter has a higher fire and flash point (> 300º C) as well as being more environmentally friendly.

Atmosphere takes a relevant importance in offshore applications. In any transformer location, the external transformer-cooling medium will be exposed to marine air, which is very humid, very salty and very variable in temperature. Liquid-filled transformers with steel tanks that can go as high as C51+M (surpassing the highest ISO 12944-2 classes) will hardly suffer in this corrosive environment. However, dry-type transformers, with their exposed windings, are much more sensitive to condensation, electrical seepage, partial discharges, cracks, temperature variations and contamination. Dry-type transformers can be protected in a hermetic envelope equipped with a heat exchanger, an air-treatment unit and force ventilation; but it is costly to manufacture and worthless.

3.3.3.3. Transformer electrical parameters

Finally, the transformer selected to step up the voltage from the generator to a suitable voltage level for the power transformer substation is a 4 MVA 30kV/690 V liquid-filled transformer, located inside the tower.

According to the ideal transformer equation:

$$\frac{\mathrm{N_p}}{\mathrm{N_s}} = \frac{\mathrm{V_p}}{\mathrm{V_s}} = \frac{\mathrm{I_s}}{\mathrm{I_p}} \rightarrow \mathrm{I_s} = \mathrm{I_p} \times \frac{\mathrm{V_p}}{\mathrm{V_s}} = \left\{ \mathrm{I_p} = \frac{\mathrm{P}}{\sqrt{3} \times \mathrm{V_p}} = \frac{3.6 \times 10^6}{\sqrt{3} \times 690} = 3012.2\ \mathrm{A} \right\}$$
$$= 3012.2 \times \frac{690}{30 \times 10^3} = 69.28\ \mathrm{A}$$

The transformer steps up the voltage from 690 V to 30 kV, at the same time, the current is stepped down from 3012.2 A to 69.28 A; therefore the power transmission cost due to Ohmic resistance is considerably reduced.

Neither transformers for this application nor data sheets exist in the market by default, so they require to be ordered specifically for every project. Pauwels has a large experience in liquid-filled transformers and has a good relationship or partnership with Siemens, so it seems proper to order the transformers to this company.

3.3.4. Inter-Turbine Array Cables

Having several turbines connected through a 33 kV submarine cable, each end of the cable is ended onto the medium voltage switchgear located within the turbine power. Due to this connection, the operating voltage for the inter-turbine cable is limited to 36 kV. These cables would also connect the array with any offshore substation.

3.3.4.1. Some factor that need to be previously considered

The design of a submarine cable system for offshore wind farms will be influenced by a number of factors. Some of them are generic, while others are project-specific:

- Connection voltage: offshore wind farm projects need to be connected to regional distribution networks, rather than to the national transmission system.
- Cable design: three-core submarine cables using solid insulation (ERP or XLPE) are typically used for operation at voltages up to 132 kV. Higher voltage cables that use oil as an insulating medium are not deemed to be environmentally acceptable due to the potential risks associated with oil leakage in the near shore environment.
- Turbine size: current offshore wind farm developments use 3 MW and 3.6 MW machines and 5 MW turbines are already projected.
- Distance to shore: the use of a single 132 kV cable to shore provides a cost-effective alternative to the use of three or four 33 kV, but this solution requires an offshore substation in order to step up to 132 kV from the wind farm collection voltage (usually 33 kV).

3.3.4.2. Anatomy of a submarine cable

- Insulation

  Three types of cable insulation are in common use for long distance submarine transmission for medium and high voltage.

  – Low-pressure oil-filled (LPOF) or fluid-filled (LPFF) cables, insulated with fluid-impregnated paper, have widely been used for submarine transmission; but, the cost of the auxiliary equipment, the environmental risks and the development of lower-cost alternatives with lower losses, have all contributed to the reduced use of LPFF cables in recent years.

  – Cross-linked polyethylene (XLPE, also known as PEX) is lower cost than LPOF of a similar rating and has lower capacitance, leading to lower losses for AC applications.

  – Ethylene propylene rubber (EPR), which has similar properties to XLPE at lower voltages, but at 69 kV and above, has higher capacitance.

- Conductors

  The conductor in medium and high voltage cable is commonly copper. Its section is function not only of the amperage and voltage to be carried, but also the cable length, insulation type, laying formation, burial depth, soil type and electrical losses.

- Number of conductors

  When possible, all three phases are bundled into one “three-core” cable because of cost reduction. It also produces weaker electromagnetic fields outside the cable and has lower induced current losses than three single core cables laid separately. However, as the load requirements and conductor diameter rise, a three-core cable becomes unwieldy and no longer feasible.

- Screening

  A semiconductive screening layer, of paper (LPOF, LPFF) or extruded polymer (XLPE and EPR), is placed around the conductor to smooth the electric field and avoid concentrations of electrical stress, and also to assure a complete bond of the insulation to the conductor.

- Sheathing

  Outside the screening of all the conductors is a metallic sheathing, which helps to ground the cable as a whole and carries fault current if the cable is damaged. In AC cables, current will be induced in this sheath, leading to circulating sheath losses. ERP insulation does not require a metal sheath.

- Armor

  An overall jacket and then armoring complete the construction. Corrosion and marine creatures protection will be applied to the armor.

- Fiber optic

  As it will be developed further, fiber optic cables for communications and remote control can be bundled into the cables.

The following picture shows the anatomy of a submarine cable for offshore applications:

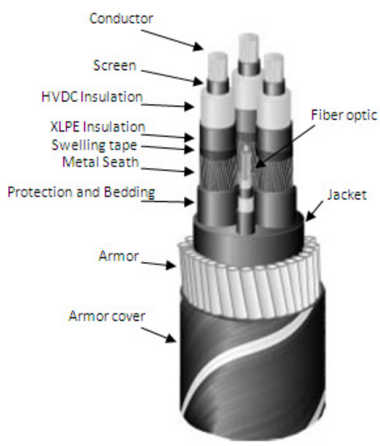
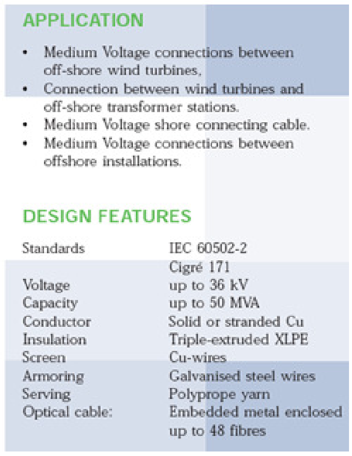


Figure 3.5. Anatomy of ABB’s XLPE submarine cable

3.3.4.3. Cable description

ABB's XLPE cable has been chosen for the turbines interconnection and to the offshore substation due to ABB's long experience and suitability for offshore applications. In the image on the right are summarized its main design features.

The rugged design of cable provides a long service life under harsh conditions. The cable is suitable for operation under all climate conditions in both salt and fresh water. It does not contain oil or other toxic components. It can be installed on all types of seabed, like sand, sediment, rocks and reefs; due to its design the cable does not emit electric fields under balanced load conditions. The magnetic field from the cable is negligible. After the useful lifetime the cable can easily be recovered and recycled.



APPLICATION

- Medium Voltage connections between off-shore wind turbines,
- Connection between wind turbines and off-shore transformer stations.
- Medium Voltage shore connecting cable.
- Medium Voltage connections between offshore installations.

DESIGN FEATURES

Standards	IEC 60502-2 Cigré 171
Voltage	up to 36 kV
Capacity	up to 50 MVA
Conductor	Solid or stranded Cu
Insulation	Triple-extruded XLPE
Screen	Cu-wires
Armoring	Galvanised steel wires
Serving	Polyprope yarn
Optical cable:	Embedded metal enclosed up to 48 fibres

Figure 3.6. ABB's cable specification

The cable configuration has been designed as can be seen in the picture below: 7 arrays of 6 turbines each one are used to develop the power from the turbines to the offshore substation. The longest array measures 6420 m and the sum of the seven arrays is 40140 m.

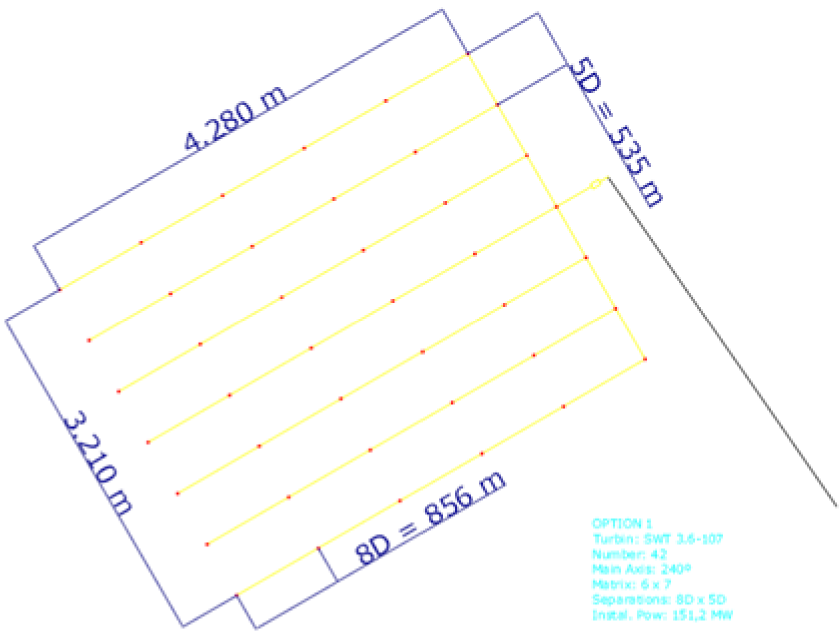


Figure 3.7. A scheme of the arrays

As it is shown in the following ABB cable specification table, the suitable conductor section for 6 turbines connection (30 kV, 4 MVA) is 185 mm^2.

Conductor mm²	Cable dia. mm	Mass in air, kg/m	Ratings at 33kV Seabed temp, °C	Current, A	Power, MVA	Losses at full load Per phase, W/m
185	107	17	10	480	27.4	32.5
			20	449	25.7	28.4
240	111	19	10	549	31.4	33.7
			20	513	29.3	29.5
300	117	22	10	611	34.9	34.9
			20	572	32.7	30.5
400	122	25	10	681	38.9	36.3
			20	637	36.4	31.7
630	138	33	10	830	47.4	39.2
			20	776	44.4	34.3
800	147	40	10	896	51.2	40.7
			20	838	47.9	35.7

Ratings are calculated for 1.0 m burial depth in sea floor with 1.0 K·m/W thermal resistivity. Ratings for other burial conditions can be obtained from ABB Power Technologies.

Table 3.2. Sections of ABB's XLPE submarine cables

3.3.5. Offshore Substation

The function of the substation is to convert the energy produced in the offshore wind farm from the 33 kV level to 132 kV, which prevents grid losses.

A description of three precedents, all fabricated by Bladt Industries, is exposed in the following table:

	Nysted, Denmark	Lilgrund, Sweden	Q7, The Netherlands
Farm power (MW)	165.6	110.4	120
Technology	HVAC	HVAC	HVAC
Voltage conversion (kV)	33 - 132	33 - 132	22 - 132
Weight (tonnes)	670	650	650
Deck area (sqm)	805	-	888
Diameters (m)	-	22	-
Height (metres above sea)	25	22	30

Table 3.3. Bladt's offshore substations

Nysted is the most similar in power to the wind farm projected and it shows the same voltage conversion; therefore, its dimensions can be used as a reference for the current case.

The main item in the offshore substation is the 180 MVA 33/132 kV transformer, but there will be also a medium-voltage and a high-voltage switchgear.

A 225 kV emergency diesel generator may be also included in order to establish an auxiliary supply of electricity to the substation as well as to the turbines. In addition, it is required for maintaining navigation and for keeping all essential equipment, such as climate conditioning and control and safety systems operating in case the connection to shore is cut off for a long period of time. The diesel generator will be installed in a container, designed according to offshore standards.

As it will be discussed later, HVAC requires a system for reactive-power compensation based on SVC (Static Var Compensator) technology. It will be installed at the beginning of the transmission network to provide the necessary power factor correction and improve the voltage quality.

The substation will have rooms for tools, refills and other items that could be used in maintenance operations. It will be also designed with survival rooms for technicians, intended for personnel marooned by sudden weather changes. Each area should be carefully assessed for fire and explosion risk and protection structures may be designed accordingly.

Regarding materials, composite multi-layer structure is virtually inert; therefore, it provides corrosion and weather resistance. Composite panels can be mounted on a corrosion resistant steel frame to resist severe blast and environmental wind and snow loads, providing an extremely rigid but lightweight structure. Blast relief vents may be included within the design to prevent overpressure build up whilst allowing quick and easy installation.

The substation is to be placed on a driven monopile, which may be able to handle constant wave impact. It will be assembled onshore and transport on a tow craft to the wind farm where it will be lifted into place by a floating crane.

Figure 3.8. Nysted's offshore substations

For HVDC transmission system, the AC electrical power from the offshore wind farm would be converted into HVDC using an offshore substation. Afterwards, the power would be transmitted through a submarine cable to a land based electrical network where it would be converted back again to HVAC using another substation.

A scheme of a VSC HVDC system is shown in the following figure:

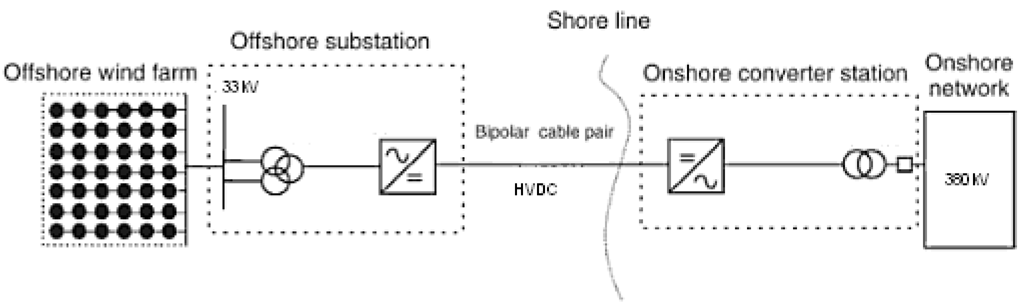


Figure 9. VSC HVDC transmission system scheme

In general, the size of an AC offshore substation will be only about a third of the size of the corresponding HVDC solutions, owing to the significant space required by the converter stations; therefore, it means a higher cost. For onshore HVDC substations, LCC technology needs considerably more space than do VSC based systems.

Regarding submarine cables, the investment costs for a bipole DC cable and a single three core 132 kV XLPE AC cable with a maximum length of 200 km are very similar, with de DC cable probably having a slight cost advantage over the AC cable. However, cost of VSC converters is up to 10 times higher than that of an HVAC infrastructure.

3.4. TRANSMISSION SYSTEM

3.4.1. Alternatives to the Transmission System to the Grid

Two alternatives are offered for connecting offshore wind farms to the main grid: High Voltage Alternative Current (HVAC) and High Voltage Direct Current (HVDC), and two technologies can be considered for HVDC: based in a Line Commutated Converter (LCC) and in a Voltage Source Converter (VSC).

Nowadays, the majority of existing offshore wind farms has chosen the solution HVAC in its transmission system. The main advantage is its significantly minor initial investment cost and the greater experience. However, for greater power and distances to the coast that at present, it could be not so feasible, mainly due to the production of important quantities of reactive power, offering the transmission technology HVDC more advantages. Therefore, it is expected that for future developments of larger and further from coast offshore wind farms, HVDC technology will be widely used.

3.4.1.1. High Voltage Alternative Current Transmission System (HVAC)

As it has been seen previously, long AC cables produce great quantity of reactive power. The charging current of the cables reduces the transmission capacity more and more. Because the cable must carry this current as well as the useful load current, this physical limitation reduces the load carrying capability of the cable. Therefore, the capacity power of the cable needs to be balanced by an additional system to absorb reactive power, like a STATCOM or SVC (static compensators) connected at the beginning and the end of the AC network. But this compensation is not efficient for long distances because of there would be a high capacity charge limiting the transmission capacity in the intermediate point of the cable.

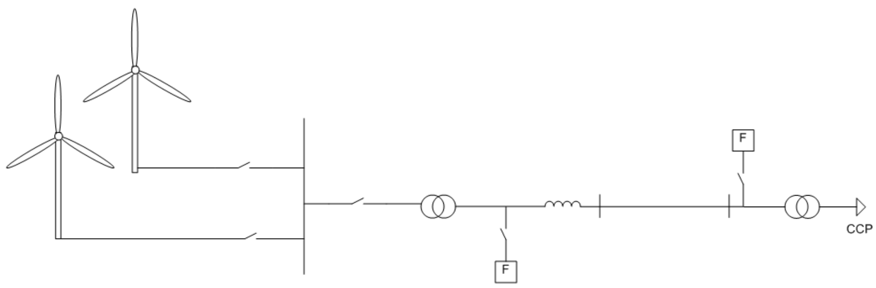


Figure 3.10. HVAC transmission system scheme

3.4.1.2. High Voltage Direct Current Transmission System (HVDC) based in a Line Commutated Converter (LCC)

It is a system based in high voltage with a converter made up of thiristors and commutated by line (LLC). It has been applied since the fifties to several types of power transmission (like submarine and underground cable transmission, asynchronous link between ac systems and long distance bulk power transmission using overhead lines), but there is little experience using this technology in marine installations.

HVDC can be used to transport more power to higher distance than HVAC, because DC wires do not generate reactive power; it allows controlling both active and reactive power, but not independently and it makes optional to operate in a variable frequency state in the wind farm internal grid. Finally, as it was mentioned before, if there is a problem in the grid, the short-circuit current is smaller than the case with HVAC.

Some of its principal drawbacks are the big space required to install the marine and land substations, converters, external equipment, transformers, etc; the higher initial investment and the necessity to compensate reactive power in both AC sides of the circuit, due to reactive power consumption by converters.

Both cables and stations of HVDC-LCC solution do not limit the transport of power to the grid, and can be reached up to 1000 MW in offshore wind farms.

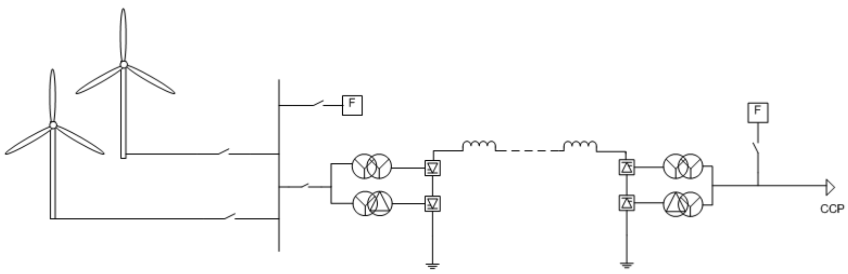


Figure 3.11. HVDC-LCC transmission system scheme

3.4.1.1. High Voltage Direct Current Transmission System (HVDC) based in a Voltage Source Converter (VSC)

It is a system based in high voltage with a voltage source converter made up of IGBTs that enables a decoupled control of both active and reactive power using a Pulse Width Modulation (PWM) in the converters control. It is also known as HVDC Light.

This system has characteristics suitable for connecting large amounts of wind power to networks, even at weak points in a network and without having to improve the short-circuit power ratio, it does not require any additional reactive power compensation, as this is inherent in the control of the converters; it can provide control functions for active and reactive power, so that both voltage and frequency can be controlled from the converter station. In particular, this allows black starting by controlling the voltage and frequency from zero to nominal; it can also provide reactive power to the wind turbines during the start up.

Some of HVDC-VSC disadvantages are the little experience in offshore wind farms; high communication frequency that provides high losses; higher initial investment due to the price of the converters and a higher limitation of maximum power to be transported (<400 MW) compared with classical HVDC thristors technology.

In comparison to HVDC-LCC, HVDC provides better stability but a lower conversion efficiency, 94% instead of 97-98% and.

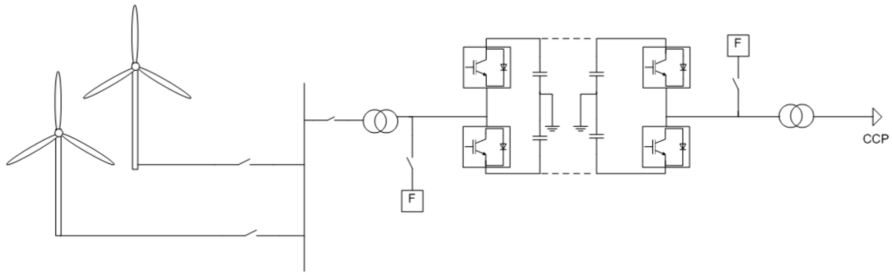
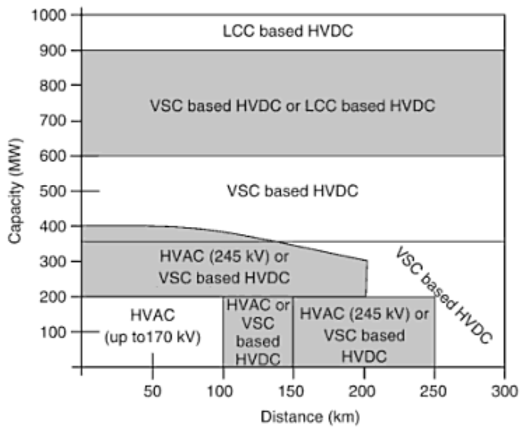


Figure 3.11. HVDC-VSC transmission system scheme

3.4.2. Comparison

In addition, some requirements must be fulfilled as for power range, voltage control, frequency control and voltage recovery after a fail. In this sense, HVAC means synchronous operation of the wind farm and the grid; all faults in the main grid directly affect the collecting grid offshore and vice versa. To mitigate this dynamic effect fast voltage control needs to be provided. On the other hand, HVDC transmission generally decouples both grids; it allows asynchronous operation of the offshore wind farm AC network and the main grid. This facilitates, in case of faults in the network, a fast return to prefault power transmission. In this sense, HVDC solution has the advantage to contribute less than HVAC one to fail current.

The following graph, taken from the book "Wind Power in Power Systems" (Thomas Ackermann, 2005), shows the capacity, distance and power limits of the transmission system; it also summarizes the complexity of selecting the correct solution.



Graphic 3.1. HVAC, LCC-HVDC and VSC-HVDC comparison

3.5. SUPERVISORY CONTROL AND DAT ACQUISITION SYSTEM (SCADA)

The SCADA (System Control and Data Acquisition) systems are a vital element that acts as a "nerve centre" for the project. It connects the individual turbines, the substation and meteorological stations to a central computer. This computer and the associated communication system allow the operator to supervise the behaviour of all the wind turbines an also the wind farm as a whole. It will keep a record of all the activity on a very short term basis and allows the operator to determine what corrective action, if any, needs to be taken. It also records energy output, availability and error signals, which will act as a basis for any warranty calculations and claims. The SCADA system also has to implement any requirements in the connection agreement to control reactive power production, to contribute to network voltage or frequency control, or to limit power output in response to instructions from the network operator.

Conceptually the SCADA system is identical to the onshore case, but will be extended to allow control and monitoring of medium-voltage switchgear and transformers in each turbine.

The SCADA computer communicates with the turbines via a communications network; candidate media for this are:

- Cooper twisted pair (RS485)

  Twisted pair copper cable using RS485 drivers is often used in data networks for short and medium length connection because of its relatively lower cost compared to optical fiber and coaxial cable. Equipment and cable is cheap, robust and readily available. Installation is straightforward and requires no special tools. Pair can be provided within submarine power cables.

  The RS-485 specification states a maximum distance of 1200 m at 4 Mbits/s. In practice, the distances achievable depends on the data rate and many manufacturers of drivers quote distances of 2500 m at rates of 9600 b/s, which makes its performance very poor for offshore applications. Other disadvantages of copper connections are the lack of inherit isolation between the machines and the drivers susceptibility to transient voltages.

- Radio telemetry

  Radio telemetry is attractive as it requires no interconnections.

  The unlicensed radio technology uses FM in the 400-500 MHz range, depending on local regulations, and works on line of sight. The distance achievable depends on the power of the transmitter, the data rate and whether directional aerials are used. On general form, it can be said that, point to point distances of up to 1 km are achievable at a data rate of 9600 b/s; for lower data rates of 1200 b/s, distances of up to 10 km are achievable.

  Licensed radios can be operated at higher powers; distances of approximately 30 km could be achievable.

  The main drawback for radio telemetry use on offshore applications is that radio communications can be affected by sea state and weather conditions.

- Fibre Optic

  Fibre optic cables offer higher bandwidth communications over longer distances. Two types of cable are available:

  - Single mode cable: slightly cheaper, lower losses but requires laser based drivers.

- Multi mode cable: used with cheaper LED based drivers.

Both single and multi mode cable give galvanic isolation and immunity to electrical noise and can be provided within submarine cables.

The bandwidth and distance achievable depends on the cable drivers; for single mode cables (laser based drivers), data rates of up to 2 Gb/s are available over distances of up to 100 km; with multi mode cables (LED based drivers), data rates of up to 100 Mb/s are achievable over distances of up to 6 km.

The disadvantages of fibre optic cable are the special tooling required for making connections and its less robustness than copper's.

The SCADA system can be either provided by the turbine supplier, or by an independent one. The first option offers more contractual simplicity; on the other hand, the major advantages of an independent supplier are the identical data reporting and analysis formats irrespective of wind turbine, which is crucial for wind farm owners or operators who have projects using different wind turbines; and the transparency of calculation of availability and other possible warranty issues.

3.5.1. Topology

Fibre optic cable has been chosen for the offshore wind farm projected, following the current trend and taking into account the different characteristics and limitations of the technology available previously exposed.

The optical-fibre connection will run in the marine cable at the seabed, which helps to reduce the high cost of laying submarine cables. The selected cable, shown in the following picture as before, is an ABB's XLPE cable where the optical-fibre connection is the small, thin to the centre while the large rings carries the three phases of the electricity produced.

The SCADA system will be provided by an independent supplier as it facilitates the coordination of different parks for owners and system operators. It can be also negotiated with ABB, since the company has large experience in SCADA systems (onshore wind farms and also different offshore applications).

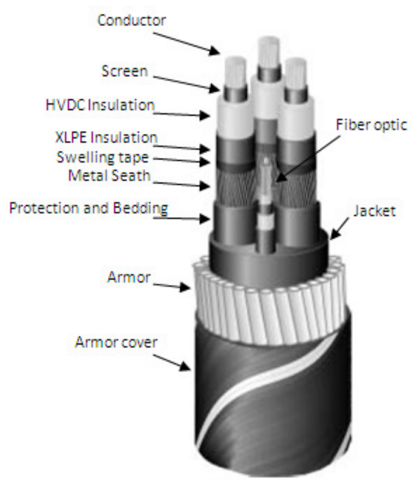


Figure 3.123. Anatomy of ABB's submarine cable

Each offshore wind turbine will be equipped with a network-base monitoring computer. It will have its own network address, allowing communication with the wind turbine via the Internet. This setup gives the monitoring system several advantages over conventional monitoring systems. Service technicians can download drawings, tables, manuals, etc., when they perform service checks. E-mail allows the turbine to communicate directly with the service department and/or sub-suppliers. This makes for fast, easy on-site solutions to problems. In addition, the monitoring system can supply more – and more detailed – information, which is expected to increase reliability.

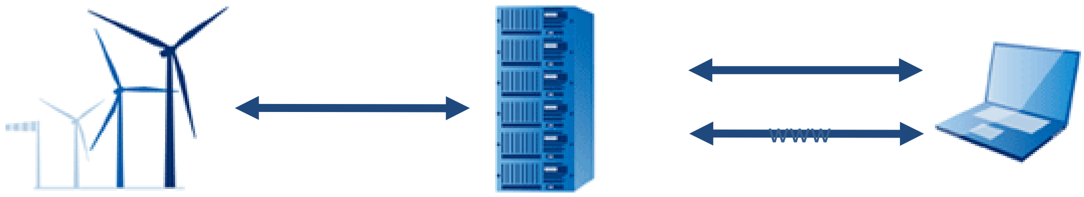


Figure 3.14. SCADA communications scheme

As an extra safety facility, the turbine will also have a conventional monitoring system, which will be directly hooked up to an optical-fibre connection, and which will operate independently of the network-based system.

The SCADA communications network can also be used for voice communications between support vessels and maintenance crews. Broadcast quality color video can be sent using a single fibre optic cable. Video cameras on selected turbines are included to check the sea state before dispatching maintenance crews by boat. Cameras may also help to detect unauthorized vessels fishing, or anchored where they could damage submarine cables.

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4. Environmental Impact Study on the Offshore Wind Farm

CONTENTS

4.1. INTRODUCTION DOCUMENT

4.1.1. Environmental Impact Study Identification

The project subject to an Environmental Impact Study is the construction and implementation of an Offshore Wind Farm in the North Sea, about 45 km north of the island of Borkum (54º 01'N, 06º 35'E), in an area called "Northern Borkum", adjacent to the FINO[19] Research Platform.

4.1.2. Environmental Impact Study Justification

Offshore wind farms are a renewable, but not entirely conflict-free form of power generation. Not only the effects on competing maritime uses, but also the marine environment must be taken into account in the authorisation of such wind farms. For the approval of offshore wind farms in the German Exclusive Economic Zone (EEZ), the EU's Environmental Impact Assessment (EIA) directives and, if NATURA 2000 areas are involved, the appropriate assessment according to the Habitat Directive, are legally stipulated. In future, in the context of the spatial planning control of wind energy use, the Strategic Environmental Assessment (SEA) will also be mandatory in the German EEZ.

The approval or rejection of offshore wind farms is regulated by the Marine Facilities Ordinance. Besides adverse effects on the safety and efficiency of navigation there is only one other reason to reject an offshore project: adverse effects on the marine environment.

Therefore, within the licensing procedure there is a strong focus on environmental aspects. Additionally, applicants have to carry out an Environmental Impact Assessment (EIA) according to guidelines of the Federal Maritime and Hydrographic Agency (BSH) before a decision is made by BSH.

4.1.3. Definition of Objectives

The final objectives or intentions that the Study of Environmental Impact tries to obtain are detailed below:

General Objective

To anticipate, to predict and to look into the possible consequences that the installation and later operation of the Offshore Wind Farm will have on the environment. And to establish the necessary preventive and remedial actions, in order to avoid and to eliminate those effects originated by the Offshore Wind Farm or to reduce them to acceptable levels.

Specific Objectives

To:

- ✓ Analyze the main characteristics of the Offshore Wind Farm.
- ✓ Identify the surroundings affected by the construction and put into operation of the Offshore Wind Farm.

[19] **F**orschungsplattformen **I**n **N**ord- und **O**stsee (Research Platforms in the North Sea and Baltic).

- ✓ Strictly fulfil the effective legislation applicable to the different phases and scopes of the Study.
- ✓ Collaborate with the sustainable development of the zone where the project is located.
- ✓ Conserve the surroundings and the natural resources of the affected zone.
- ✓ Identify the different elements from the geophysical environment that can be affected by the project.
- ✓ Identify the elements of the biotic environment that can be affected by the Offshore Wind Farm.
- ✓ Study the flora of the area affected by the project.
- ✓ Know the fauna of the affected zone.
- ✓ Identify the elements of the socioeconomic and cultural environment that can be affected by the Offshore Wind Farm.
- ✓ Develop the procedure of evaluation of the environmental impacts detected.
- ✓ Develop preventive and remedial measures.
- ✓ Propose a plan of monitoring and environmental control.

Operative Objectives

To:

- ✓ Describe the main characteristics of the project during the construction stage.
- ✓ Identify the possible actions of the project that are susceptible to generate impacts, classifying them based on the phase of the project in which they can appear or be generated.
- ✓ Evaluate the impact of sound emissions and vibration.
- ✓ Value the scenic quality of the landscape.
- ✓ Characterize and identify the Environmental Impacts generated by the Offshore Wind Farm.
- ✓ Make a matrix of impacts identification as well as a complex matrix cause-effect of valuation of environmental impacts.

4.1.4. Justification of the Project's Location

The area "Northern Borkum" is suitable for the use of wind energy, due to the fact that it shows comparatively low water depths; between 23 meters in the southeast and 33 meters in the north.

The area shows an ecosystem with only low occurrence in protection-needed ways of life. During approval procedures for some of the projects lying within area, extensive environmental examinations of several years were executed. Results suggest a low relevance of the pilot's areas and the adjacent areas for protection-worth ways of life and the sea environment.

In addition, the proposed area lies within sufficient distance to the recognized sea lanes essential to international navigation in this area: to the traffic division areas (VTG) German Bight Western Approach (GBWA) and Terschelling German Bight (TGB) as well as the Emsansteuerung.

Figure 4.1 shows three different divisions of the “Northen Borkum” area. Our project is located within the partial surface II. As can be observed, our project does not lie within any Natura 2000 area.

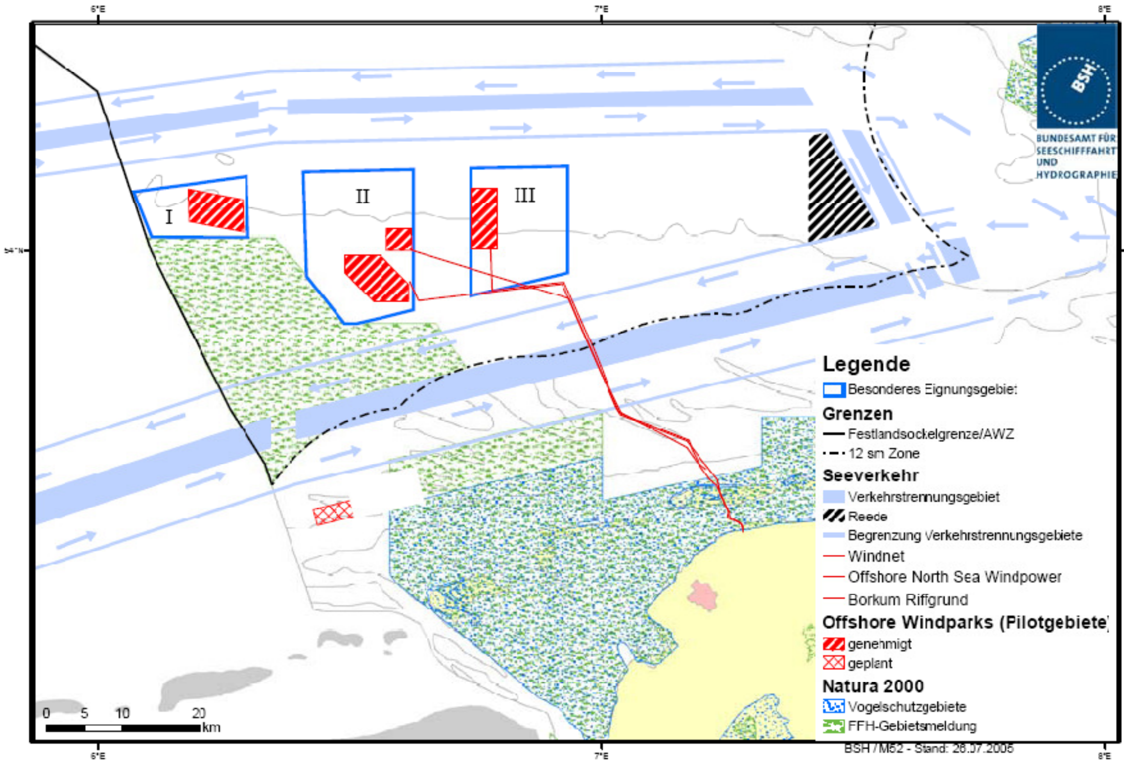


Figure 4.1. Subdivision and surrounding uses of "Northern Borkum" area.

4.1.5. Boundary of the Surroundings affected by the Project

Considering the characteristics of the construction and implementation of this Offshore Wind Farm in Germany, in the “ Northen Borkum” area, and the environment surrounding the location of the project, the area studied will be the German Bight[20] of the North Sea.

[20] **German Bight** is the south-eastern bight of the North Sea bounded by the Netherlands and Germany to the south, and Denmark and Germany to the east. To the north and west it is limited by the Dogger Bank. The bight contains the Frisian and Danish Islands. The Frisian Islands and the nearby coastal areas are collectively known as Frisia. The southern portion of the bight is also known as the Heligoland Bight. Between 1949 and 1956 the BBC Sea Area Forecast (Shipping Forecast) used "Heligoland" as the designation for the area known as the German Bight.

4.1.6. Legal Framework

4.1.6.1. European Union Regulations

4.1.6.1.1 General Regulations regarding to Environmental Impact Assessment.

RANGE	TITLE
Directive	*Directive on the Assessment of the Effects of Certain Public and Private Projects on the Environment (85/337/EEC) (OJ L175 5 July 1985)*
Directive	*Directive 97/11/EC, which amends Directive 85/337/EEC.*
Convention	*Espoo Convention on Environmental Impact Assessment in a Trans boundary Context, entered into force in 1997.*
Directive	*Directive 2001/42/EC on the Assessment of the Effects of certain Plans and Programmes on the environment.*

4.1.6.1.2 Sectorial Regulations.

SECTOR	SCOPE	RANGE	TITLE
Environment	General	Agreement	*Agreement of the Representatives of the Governments of the Member States meeting in council of 5 March 1973 on information for the Commission and for the Member States with a view to possible harmonization throughout the Communities of urgent measures concerning the protection of the environment.*
		Decision	*Council Decision 76/161/EEC of 8 December 1975 establishing a common procedure for the setting up and constant updating of an inventory of sources of information on the environment in the Community*
		Directive	*Council Directive 82/501/EEC of 24 June 1982 on the major-accident hazards of certain industrial activities.*
		Regulation	*Council Regulation (EEC) No1210/90 of 7 May 1990 on the establishment of the European Environment Agency and the European Environment Information and Observation Network.*
		Directive	*EC Council Directive 91/244, 6 March which amends EC Council Directive 79/409/EEC.*

SECTOR	SCOPE	RANGE	TITLE
Environment	General	Directive	*Council Directive 90/313/EEC on the freedom of access to information on the environment*
		Resolution	*Resolution 93/C 138/0 on an environment and sustainable development community program on policy and action.*
Atmospheric Means	Air Pollution	Directive	*Council Directive 80/779 of 15 of July, on air quality limit values and guide values for sulphur dioxide and suspended particulates, as last amended Directive 89/427/EEC.*
		Directive	*Directive 85/203 EEC (1985) Air Quality Standards for Nitrogen dioxide.*
		Protocol	*Amendent to The Montreal Protocol on Substances that Deplete the Ozone Layer of 31 December 1991.*
		Directive	*Directive 96/62/CE on Ambient Air Quality Assessment and Management of 27 of September 1996.*
	Noise	Directive	***Council Directive 70/157/EEC of 6 February 1970 on the approximation of the laws of the Member States relating to the permissible sound level and the exhaust system of motor vehicles***
		Directive	***Council Directive** 77/212, of 8 of March,which amends the **Council Directive** 70/157.*
		Directive	***Council Directive** 79/113 /EEC, which determines the noise emissions of construction plant and equipment to cover compressors, cranes, welding generators, excavators, power generators, concrete-brakers, loaders, dozers and picks.*
		Directive	***Council Directive** 92/97 of 10 of November, amending **Council Directive 70/157/EEC**.*
Hydric Means	Water Quality	Directive	*Directive on Pollution caused by Certain Dangerous Substances Discharged into the Aquatic Environment of the Community (76/464/EEC) (OJ L129 18 May 1976.*
		Directive	*EC Groundwater Directive (80/68/EEC OJ L20 26 January 1980)*
		Directive	*Directive 80/778/EEC of 15 July 1980 relating to the quality of water intended for human consumption.*

SECTOR	SCOPE	RANGE	TITLE
Hydric Means	Discharges	Directive	*Council Directive 86/280/EEC of 12 June 1986 on limit values and quality objectives for discharges of certain dangerous substances.*
		Directive	*Council Directive 88/347/EEC amending Annex II to Directive 86/280/EEC.*
		Directive	*Council Directive 90/415/EEC of 27 July 1990 amending Annex II to Directive 86/280/EEC*
		Directive	*Urban Wastewater Treatment Directive (91/217/EEC).*
Terrestrial Means	Waste	Directive	*EC Waste Framework Directive 91/156*
		Directive	*EC Directive 91/689/EEC*
		Directive	*Council Directive 75/442/EEC of 15 July 1975 on Waste.*
		Directive	*Directive 78/319 on toxic and dangerous waste.*
		Directive	*Council Directive 94/31/EC of 27 June 1994 amending Directive 91/689/EEC on hazardous waste.*
		Decision	*Council Decision 22/12/94 which settles down a list of dangerous waste by virtue of section 4 of article 1 of Directive 91/689*
		Decision	*Council Decision of 17 of April of 1996 , which settles down a form for the presentation of information in accordance with section 3 of article 8 of Directive 91/689.*
		Decision	*Commission Decision of 24 of May 1996 adapting Annexes IIA and IIB to Council Directive 75/442/EEC on Waste.*
Nature Conservation	General	Directive	*EC Council Directive 92/43 /EEC on the conservation of natural habitats.*
		Regulations	*Council Regulation (EEC) No 3528/86 on the protection of forests against atmospheric pollution*
		Regulations	*Commission Regulation (EEC) No 1696/87 of 10 June 1987 laying down certain detailed rules for the implementation of Council Regulation (EEC) No 3528/86 on the protection of the Community's forests against atmospheric pollution (inventories, network, reports)*
	Fauna	Directive	*EC Council Directive 79/409/EEC on the conservation of wild birds (The Wild Birds Directive).*
		Directive	*EC Council Directive 91/244, 6 March which amends EC Council Directive 79/409/EEC.*
		Directive	EC Council Directive 94/24, 8 June, which amends the Anex II of Directive 79/409.

4.1.6.2. Germany Regulations

Renewable Energy Sources Act-EEG

In Germany, generating electricity by wind-powered plants is promoted by the Act on Granting Priority to Renewable Energy Sources (*Renewable Energy Sources Act - EEG*). This act is an effective and efficient instrument for increasing the use of renewable energies on the road towards a sustainable energy system. The core elements of the EEG are:

- ✓ the priority connection of installations for the generation of electricity from renewable energies and from mine gas to the general electricity supply grids;

- ✓ the priority purchase and transmission of this electricity; a consistent fee for this electricity paid by the grid operators, generally for a 20-year period, for commissioned installations, this payment is geared around the costs, and

- ✓ the nationwide equalisation of the electricity purchased and the corresponding fees paid.

Marine Facilities Ordinance

Under § 2 of the Marine Facilities Ordinance, wind farms in the EEZ require the approval of the Federal Maritime and Hydrographic Agency (BSH). Such approval is a "bound decision"; that means that approval can only be denied to the applicant if reasons for refusal under § 3 are present.

Accordingly, approval must be refused "if […] the marine environment is endangered without there being any possibility of such endangerment being prevented or compensated by time limitation, conditions or stipulations.

Grounds for rejection shall in particular be present if […]

- pollution of the marine environment as per Article 1, Sect. 1 No. 4 the United Nations Convention on the law of the Sea of 10 December 1982 is to be feared; or if
- bird migration is jeopardized".

The protected assets (Table 4.1) which must in principle be taken into account in the ascertainment, description and assessment of environmental impacts are described in § 2 Sect. 1 of the Environmental Impact Assessment Act (UVPG). Since the approval for a wind farm is granted in accordance with the assessment standards stated in the Marine Facilities Ordinance, these protected assets are to be juxtaposed to the terms "marine environment" and "bird migration", and concretised in according with their specific expression in the EEZ.

Protected Assets under the EIA Act	Specification of the"marine environment" and the "bird migration" protected assets, as stated in AnIV
Human beings	Human beings
Fauna	Sea birds, migratory birds, marine mammals, fish, benthos
Flora	Esp. Growth on structures, macro-phytobenthos
Soil	Seabed, sediment structure
Water	Seawater, hydrology
Air	Air
Climate	Climate
Landscape	Landscape
Interactions	Interactions between these factors
Material assets and cultural heritage	Wrecks

Table 4.1. Protected assets under the EIA Act, and definition of protected assets as per AnlV

Licensing Offshore Wind Farms in the Territorial Sea

The territorial sea, i.e. the zone of 12 nautical miles off the German coast, belongs to the territory of the Federal Republic of Germany. The same provisions of the Federation and coastal Länder apply here as on land. Hence, the Federal Immission Control Act (BImSchG) is also applicable for the licensing of wind farms in the territorial sea. For their construction and operation wind farms require a licence pursuant to Article 4 BImSchG. The licensing procedure must be carried out by the competent immission control authority of the coastal Länder as a formal procedure pursuant to Article 10 BImSchG. The procedure involves an environmental impact assessment and public participation, since offshore wind farm projects regularly concern the construction and operation of more than 20 wind turbines.

Prior to the licence being granted, therefore, there must be an examination into whether the project complies with the regulations of the relevant *Land building code*, and whether interference with the safety and easy flow of shipping as defined in the *Federal Waterways Act* can be ruled out.

The project must be an admissible intervention in nature and landscape. In the territorial waters of the North Sea which have been designated by Land legislation as Wadden Sea National Parks, the construction and operation of an offshore wind farm is only permissible in exceptional cases.

Licensing of Offshore Wind Farms in the Exclusive Economic Zone (EEZ)

The legal situation in the Exclusive Economic Zone, which covers the marine area beyond the territorial sea, is more complex. The EEZ does not belong to the national territory of the Federal Republic of Germany. Prevailing opinion maintains that national law which applies in the national territory is only applicable in the EEZ if the legislator has expressly declared it to be so. However, the 1982 United Nations Convention on the Law of the Sea which entered into force in 1994 grants coastal states certain utilisation privileges and regulatory powers in these marine areas, including specifically for the construction and operation of installations for the generation of energy from wind (cf Articles 56 and 60).

The installations must not interfere with the use of recognised sea lanes essential to international navigation. Besides the United Nations Convention on the Law of the Sea there are numerous other international agreements which contain individual regulations on the protection of marine environments. The most important of these are the two regional agreements on the protection of the marine environment of the North-East Atlantic and of the Baltic Sea of 1992 – the OSPAR Convention (in force since 1998) and the Helsinki Convention (in force since 2000).

A further important step towards implementing the obligations under community law was achieved with the notification of a total of eight proposed sites under the Habitats Directive and two bird protection areas in the North and Baltic Seas.

In addition to the licensing of offshore wind farms, a permit must also be granted for laying the cable for the grid connection. For the Exclusive Economic Zone, this again requires a licence from the BSH, while in the territorial sea an authorisation from the river and shipping police, a permit under water law and – where applicable – an exemption from the bans of the respective national park legislation are required. In spite of the division of responsibilities, an overall assessment should be undertaken during the licensing procedure, i.e. the environmentally relevant impacts of the offshore wind park including cable connection should be jointly evaluated.

4.2. TECHNICAL DOCUMENT OF ANALYSIS OF THE PROJECT

4.2.1. Project Location

The project is located in the North Sea, in the adjacent area to the FINO 1 Research Platform, about 45 km north of the island of Borkum (54º 01'N, 06º 35'E), within the German Exclusive Economic Zone (EEZ). The site comprises 13.738 km^2. Figure 4.1 shows the location of the project.

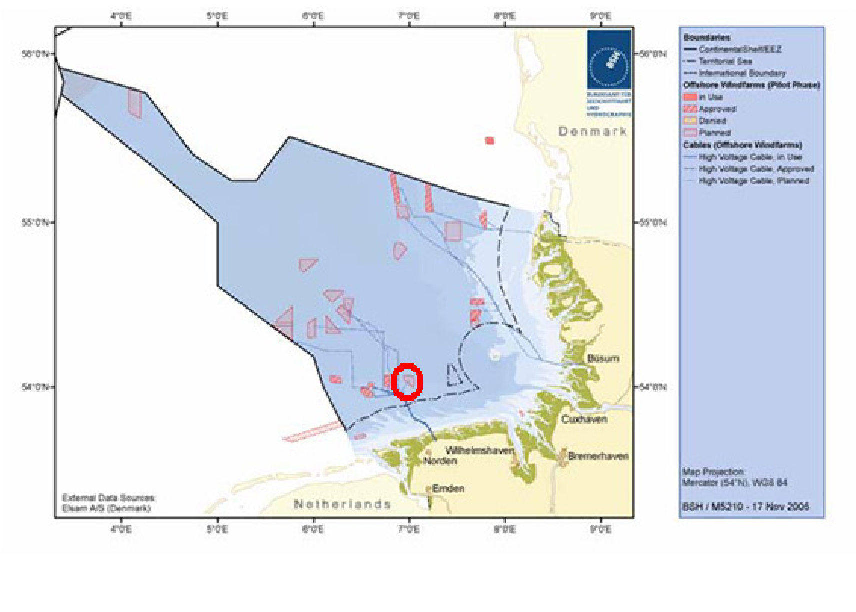


Figure 4.1. Location of the project.

4.2.2. Project Identification

- Location: **“Northern Borkum” area (North Sea)**
- Size of park: **42 turbines**
- Net Installed capacity: **150 MW**
- Production: **3,500 Net Equivalent Hours (NEH)**
- Wind turbines:
  - Type: **Siemens SWT 3.6-107**
  - Height: **80 m**
  - Diametre: **107 m**
- Cable connection: **7 three-phase cables of 33kV**

4.2.3. Actions involved in the phases of the Project.

4.2.3.1. Construction Phase

- Land occupation
- Introduction of hard substrata
- Pile driving for the foundations
- Cable laying
- Assembling of the wind turbines
- Waste production

4.2.3.2. Operational Phase

- Operation of the turbines
- Presence of the wind farm
- Waste production
- Workforce requirement

4.2.3.3. Decommissioning Phase

- Clearance of the area
- Pile removing
- Waste production

4.3. PREOPERATIONAL ENVIRONMENT OF THE SURROUNDINGS OF THE PROJECT

According to the Strategy of the German Government on the Use of Offshore Wind Energy, three offshore research platforms were to be constructed in three potentially suitable areas in close vicinity to larger offshore wind farms that are planned and applied for at the BSH.

In the years 2002 and 2003 the first German research platform for offshore wind energy deployment FINO 1 (Figure 4.2) was realized, with a view of determining the effects of such offshore plants on marine flora and fauna. FINO 1 has been in operation in the North Sea since summer 2003 with a very high availability of all measurement data.

The data obtained with this research platform will be used for the purpose of the present Environmental Impact Study.

Figure 4.2. Research platform FINO 1 in the North Sea (Photo: Hero Lang)

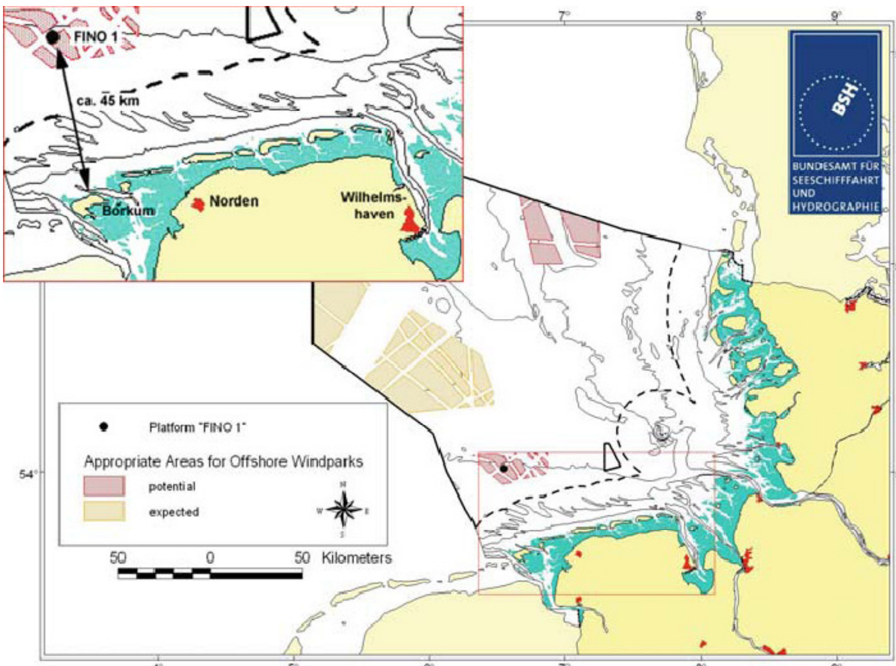


Figure 4.3. Location of FINO 1 in the North Sea (Source: BSH)

4.3.1. Birds

4.3.1.1. Bird Migration

Introduction

Annually, more than ten million birds cross the North and Baltic Seas, both during the spring and the autumn migrations, on their way between their breeding and their winter habitats.

Observations to date have indicated that the bird migration, particularly over the North Sea, proceeds largely in the form of broad-front migration, i.e. there are no particular corridors preferred by the migratory birds.

In the North Sea, two periods of intensive migration (spring, autumn) recognizably alternate with two periods of less intensive migration (summer, winter). The lowest migration intensity was found in mid-June.

Depending on species and weather conditions, migratory birds fly at very different heights, ranging from just over the water surface to several thousands metres' altitude. The construction of offshore wind parks will introduce vertical structures to a largely vacant area located at the migratory altitude of many bird species. The main danger area is the range between 20 and 200 m height. Bruderer and Liechti (2004) showed that 50% of all migrants over Switzerland and southern Germany could be detected at an altitude between 0 m and 250 or 750 m (depending on season and time of day).

Potentially two particular correlations of effects exist which could constitute endangerment to bird migration:

- ✓ the danger of collision with the turbines (bird strike), and
- ✓ the barrier effect, with forced avoidance and circumnavigation of the farms by the birds, resulting in an increased consumption of energy reserves.

Roughly 2/3 of all bird species migrate during darkness, when the collision risk with wind turbines is expected to be higher than during daylight. It has also been observed that a large number of migratory birds avoided the wind farms and consequently, at least in good visibility, did not risk collision.

Species Composition

On Helgoland, more than 425 species have been recorded, which shows the great number of species which migrate across the North Sea (Alerstam 1990).

The systematic visual daytime observations in 2003-2004 ascertained a total of 217 species (192 on Sylt, 174 on Wangerooge and 167 on Helgoland). At all sites, waterfowl, including great cormorant *Phalacrocorax carbo*, gulls and terns were the dominant groups recorded by sea-watching (Hüppop et al. 2006), with great cormorant, greylag goose *Anser anser*, pink-footed goose *Anser brachyrhynchus*, barnacle goose *Branta leucopsis*, brent goose *Branta bernicla*, common eider *Somateria mollissima*, common scoter *Melanitta nigra*, common gull *Larus canus*, black-headed gull *Larus ridibundus*, lesser black-backed gull *Larus fuscus*, sandwich tern *Sterna sandvicensis* and common tern *Sterna hirundo* being numerically the most important species. Common wood pigeon *Columba palumbus*, meadow pipit *Anthus pratensis*, white wagtail *Motacilla alba*, fieldfare *Turdus pilaris*, redwing *Turdus iliacus*, song thrush *Turdus philomelos*, Eurasian jackdaw *Corvus monedula*, brambling *Fringilla* *montifringilla*, chaffinch *Fringilla coelebs* and common linnet *Carduelis cannabina* were the most numerous species.

At the FINO 1 platform, 70 different species were verified by the automatic flight call recording. Over 70 % of the registered flight calls were thrushes, chiefly redwings, blackbirds *Turdus merula*, fieldfares and song thrushes; some 10 % were waders, primarily common redshanks *Tringa totanus*, red knots *Calidris canutus*, Eurasian golden plovers *Pluvialis apricaria*, common sandpipers *Actitis hypoleucos* and greenshanks *Tringa nebularia*. Other frequently registrated species were sky lark *Alauda arvensis*, meadow pipit, goldcrest *Regulus regulus*, European robin *Erithacus rubecula*, common starling *Sturnus vulgaris* and snow bunting *Plectrophenax nivalis*, although most of the calls made by the last four species in all likelihood involved birds resting on the platform.

Collisions

Among seabirds, reactions to offshore wind farms vary widely from species to species. While some avoid the wind farm and its surroundings after operation commenced, other seabird species remain within the wind farm area, although sometimes in reduced numbers.

A total of 442 birds of 21 species were found dead at FINO 1 between October 2003 and December 2004. Nearly all were in good physical condition, which excludes starvation as a cause of death; 245 individuals (76.1 %) had visible injuries, most commonly bleedings at the bill (41.3 %), contusions on the skull, and broken legs (16.8 %). Possibly, some birds died of exhaustion caused by flying around the platform (Hope Jones 1980). Results clearly show that the mass of birds collected had collided with the structure, and in only a few cases could starvation not be ruled out entirely. Since most birds probably fell into the sea or were taken by gulls, the actual total of collisions is presumably many times higher.

The extent to which avian migrants are likely to interact with the offshore wind farm is currently difficult to estimate (Hüppop et al. 2004, Desholm and Kahlert 2005). Especially under weather conditions with poor visibility, illuminated objects can attract nocturnal migrants in large numbers (e.g. Schmiedel 2001).

Offshore wind turbines have to be illuminated for reasons of ship and aircraft safety, too. Collision is likely to be even more pronounced at sea than on land, as there are no suitable resting places at sea for terrestrial birds, especially during nights with dense migration traffic and adverse weather conditions. There are usually only a few such nights per migration period.

Dierschke et al. (2003) assumed that an increase of the existing adult mortality rate by 0.5 - 5 %, depending on the individual species, seems to be acceptable for the 250 bird species regularly migrating across the German maritime area. Any greater loss would have to be classed as “considerable impact”.

Figure 4.4. Redwings and a few song thrushes found dead at the research platform FINO 1 in October 2004. Feathers at the rail clearly indicate collisions.

Migration Intensity, Altitude and Direction

The wind and the visibility conditions govern the migration intensity over the open sea (for details see Hüppop et al. 2006). Birds generally try to fly at altitudes at which their energy costs are lowest (Bellrose 1967, Bruderer and Lietchti 1995), which usually means that the flight altitude of low migrating birds is lower offshore than at the coast or inland (e.g. Krüger and Garthe 2001, Hüppop et al. 2004).

One possible factor is that tailwinds at low altitudes are more favourable at sea than over land. Moreover, adverse weather conditions lead to further reductions in flight altitude, so that many birds fly low over the water surface (Hüppop et al. 2004).

The flight altitude distribution may also be affected by the range of species involved. Many diurnally migrating species of waterfowl and seabirds migrate mostly at very low altitudes (Krüger and Garthe 2001, Dierschke and Daniels 2003, Hüppop et al. 2004), while arctic waders fly at very high altitudes, at least when migrating to their breeding grounds in May (Green 2003).

Reverse migration often occurs in connection with changing weather conditions, e.g. when severe weather forces the birds to turn back or when good weather periods “encourage” the birds to return to favourite stopover sites in autumn migration (Wikelski et al. 2003).

Conclusions

Large numbers of diurnal and nocturnal migrants cross the German Bight, with considerable variation of migration intensity, time, altitude and species, depending on season and weather conditions. Large numbers of nocturnally migrating birds of unknown species also cross the German Bight. Almost half the birds fly at “dangerous” altitudes, and the considerable reverse migration increases the risk of collision. Normally, migrating birds seem to avoid obstacles, even at night (Isselbächer and Isselbächer 2001, Schmiedel 2001, Desholm and Kahlert 2005), which diminishes collision risk, but increases flight costs. But at poor visibility terrestrial birds in particular are attracted by illuminated offshore obstacles.

4.3.1.2. Resting and Breeding Birds

Introduction

A total of 35 seabird species have been identified as living regularly in the German territorial waters and the Exclusive Economic Zone (EEZ) (Garthe et al. 2003a). These include birds breeding in coastal colonies and foraging offshore as well as birds wintering, moulting and/or staging during migration at sea.

In the German Exclusive Economy Zone of the North Sea, the eastern German Bight has been identified as the area most suitable for a bird reserve in terms of extent and population, and has been proposed for that purpose under the EU Birds Directive.

The construction and operation of offshore wind-power turbines involves on the one hand the risk of collision for sea and resting birds with the turbines, and on the other the possibility of disturbance effects on resting, feeding and wintering of sea birds. Dislocation and scaring-off effects are to be expected not only from windpower turbines, but also from construction and supply vehicles. As for migratory birds, so too for resting and feeding birds which live on the high seas for lengthy periods, offshore wind-power turbines may constitute a barrier. The fragmentation effect of the plant areas may separate ecologically associated resting and feeding sites.

Distribution of Seabirds

Some examples are selected in order to show the seasonal variation of seabird distribution. The complete results of recent seabird mapping in German waters are available from Garthe et al. (2003b, 2004).

- **Red-throated Diver** (*Gavia stellata*) and **Black-throated Diver** (*Gavia arctica*): In winter, the proportion of Red-throated Divers is 95 % in the German North Sea (Mitschke et al. 2001, Garthe et al. 2003b). Considerable numbers of divers are present in German waters from November to April, but their distribution changes during winter and spring. In winter, their occurrence in the North Sea is concentrated in a 20 km (Lower Saxony) to 60 km wide strip (Schleswig-Holstein) along the coast. In springtime, divers move both to the north and to the east, leading to concentrations west of the North Frisian Islands and east of the island of Rügen. From these two areas, the birds seem to depart to their breeding areas in northern Eurasia.

- **Common Scoter** (*Melanitta nigra*): The Common Scoter is one of the most abundant seabirds in German waters. Whereas these birds are restricted to coastal areas in the North Sea, they are present further offshore in the Baltic Sea.

- **Common Guillemot** (*Uria aalge*): Whereas in summer, Guillemots are mainly restricted to the sea area around Helgoland (Dierschke et al. 2004), they are dispersed throughout most of the German EEZ in winter time.

Vulnerability of Seabirds to Offshore Wind Farms

During the MINOS[21] project, an index was developed to obtain species specific estimates of vulnerability of seabirds to offshore wind farms (for details see Garthe and Hüppop 2004). Nine factors which are thought to be relevant in the context of disturbance and collision risk were selected:

1. flight manoeuvrability,
2. flight altitude,
3. percentage of time flying,
4. nocturnal flight activity,
5. disturbance by ship and helicopter traffic,
6. flexibility in habitat use,
7. bio-geographic population size,
8. adult survival rate and
9. European threat and conservation status.

Hence, these factors represent flight behaviour (1 - 4), general behaviour (5 - 6) and status (7 - 9). For each species, each factor was scored from 1 (low vulnerability) to 5 (high vulnerability), resulting in Species Sensitivity Indices (SSI).

For those species occurring in the German sector of the North Sea, the highest SSI values were calculated for the Red-throated Diver and the Black-throated Diver, the Velvet Scoter (*Melanitta fusca*) and the Sandwich Tern (*Sterna sandvicensis*), whereas vulnerability according to SSI was the lowest for a number of gull species and for the Northern Fulmar (*Fulmarus glacialis*).

By multiplying the SSI values with the density of the respective species, the question of vulnerability can be transferred to given areas of sea. Summing up the resulting values of all species yields the area-specific Wind Farm Sensitivity Index (WSI). This procedure was applied to the German North Sea. It became obvious that especially the coastal areas of the south-eastern North Sea must be regarded as vulnerable to wind farms (Figure 4.5).

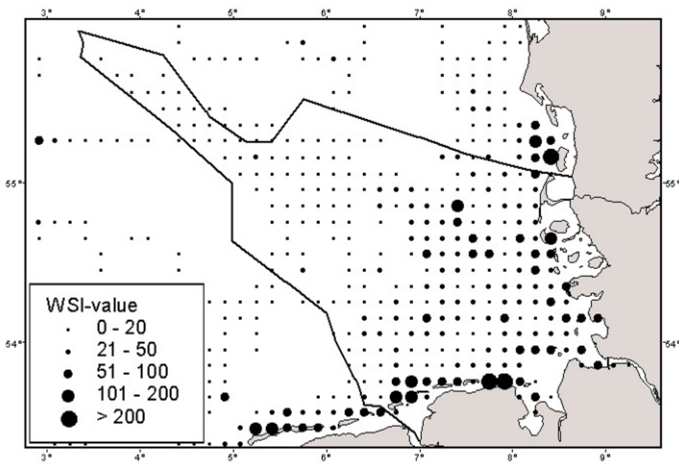


Figure 4.5. Spatial distribution of the wind farm sensitivity index (WSI) values (all seabird species combined) in the south-eastern North Sea during springtime (March - May) 1993 - 2003. (Garthe and Hüppop 2004)

[21] MINOS Project: Telemetry and seals. Harbour seals in the German Bight were equipped with dead-reckoners and satellite transmitters to track them while they were hauled out on land and foraging at sea.

Important Areas for seabirds

Effects of offshore wind farms on seabirds impact their population dynamics as soon as either their mortality rate or reproduction rate are affected to a degree that changes the population size. Figure 4.6 shows the important bird area in the North Sea, which is out of the boundary of the proposed offshore wind farm.

Based on the commonly used criteria from the Ramsar Convention (Atkinson-Willes 1972), the occurrence of 1 % of a population was considered to be the level that indicates that a given area is important for a species.

In the territorial waters and the Exclusive Economic Zone, a total of 26 offshore wind farms has been proposed. The size of all proposed wind farms is 1,297 km². Seabird densities were calculated for all four seasons for seven areas that contain one or more wind farms each (Figure 4.7). In order to obtain an estimate of how many seabirds live in the wind farm areas, bird densities were multiplied by the size of the wind farms (Northern Gannet *Sula bassana*, Lesser Black-backed Gull *Larus fuscus*, Sandwich Tern). For those species which were observed to strongly avoid wind farms, with distances kept from turbines of 2 km or more (Redthroated Diver, Common Guillemot; Petersen 2005, Dierschke and Garthe 2005), a buffer zone of 2 km was included in the calculation.

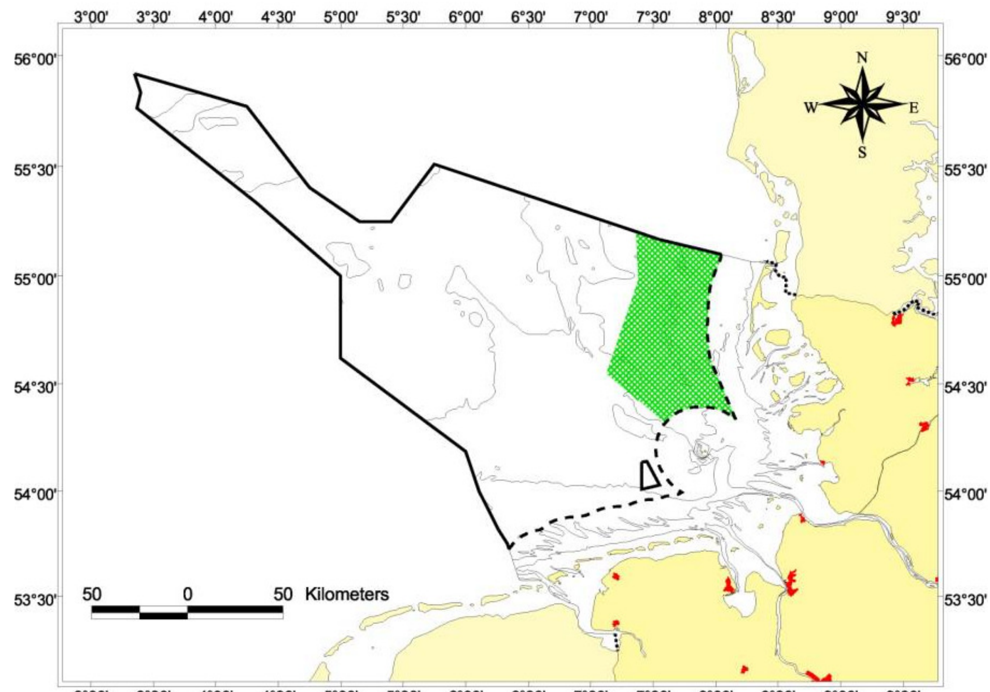


Figure 4.6. North Sea: Important Bird Area.

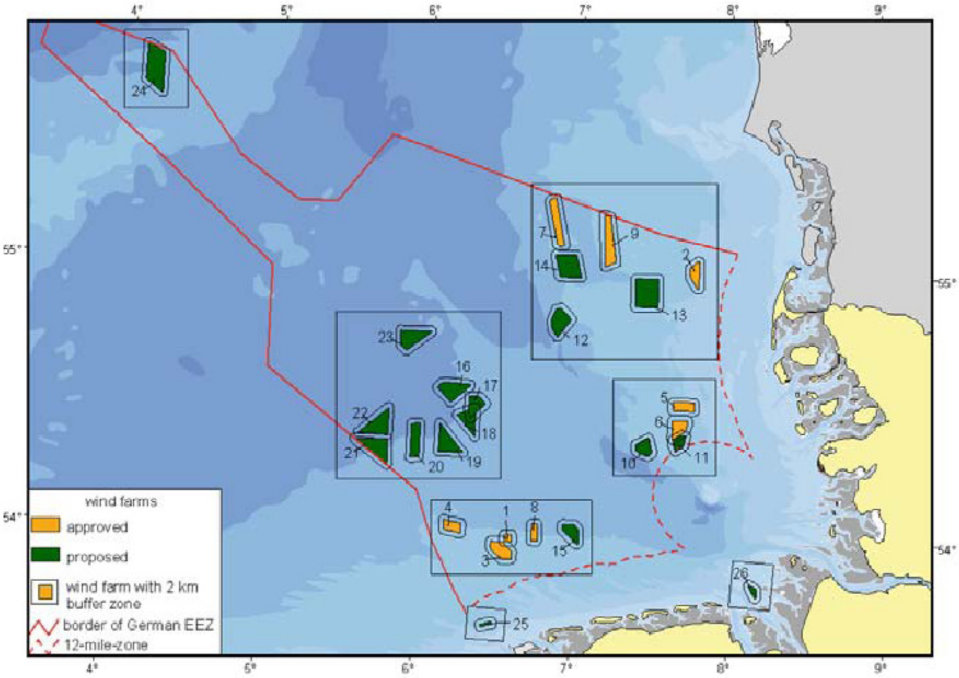


Figure 4.7. Wind farms proposed and/or approved in the German sector of the North Sea by August 2005. Rectangles indicate the areas used for the calculation of seabird densities. Approved: 1 Borkum West (12 turbines), 2 Butendiek (80), 3 Borkum Riffgrund (77), 4 Borkum Riffgrund West (80), 5 Amrumbank West (80), 6 Nordsee Ost (80), 7 Sandbank 24 (80), 8 ENOVA Offshore Northsea Windpower (48), 9 DanTysk (80)

Based on the proportions of selected German seabird populations affected by approved and proposed offshore wind farms in the German sector of the North Sea, habitat loss can be expected for Red-throated Diver, Northern Gannet and Common Guillemot, whereas in the other two species due to flights through wind farms a loss of foraging habitat and mortality from collisions cannot be excluded.

Conclusions

In conclusion, it is obvious that depending on avoidance behaviour and collision risk as well as on the proportions of populations affected, the impact of offshore wind farms in the German sector of the North Sea on seabird populations differs considerably. The example of Red-throated Divers and Common Guillemots shows that large parts of the German Bight would be excluded from use by these species. This has to be taken into account in the process of commissioning.

4.3.2. Marine Mammals

Introduction

Marine mammals are at the end of the food-chain in the ecosystem. Due to their size, they have no natural enemies in the North Sea. However, the marine mammals living in the project area are endangered by a multitude of anthropogenic effects.

The operation of offshore wind energy plants always involves acoustic emissions into the body of water, both during the construction phase and the operational phase of the plants. While the acoustic emissions only occur occasionally and temporarily during the construction phase, the noise is permanent during the regular operation of the plants. Due to the large number of individual plants, an extensive and permanent noise burden in the sea.

Species Composition

Three marine mammals species are native to the German North Sea:

- the harbor porpoise *(Phocoena phocoena),* which is the most common whale species there;
- the harbor seal *(Phoca vitulina)* and
- the grey seal *(Halichoerus grypus)*

Moreover, a number of other species of whale and seal are also encountered, although their appearance is rather rare in the German waters.

Harbour Porpoises

The harbour, or common porpoise (*Phocoena phocoena*) is the smallest cetacean inhabiting temperate to cold waters throughout the northern hemisphere. It is the only cetacean species regularly found in both the German North and Baltic Seas (Reijnders 1992, Benke and Siebert 1994, Schulze 1996, Benke et al. 1998, Hammond et al. 2002, Siebert et al. accepted).

Summer distribution (May to August) in the German North Sea for 2002 and 2003 showed an uneven distribution of porpoises throughout the German Bight (Figure 4.8). Highest densities were observed around the so-called 'Amrum Aussengrund' which includes the area off the island of Sylt close to the Danish border. A north-south density gradient was observed along the coastline. The lowest densities were found off the East Friesian Islands. The aerial surveys revealed that harbour porpoises were present in the farthest reaches of the German EEZ (Doggerbank), although in slightly lower densities than at the 'Amrum Aussengrund'.

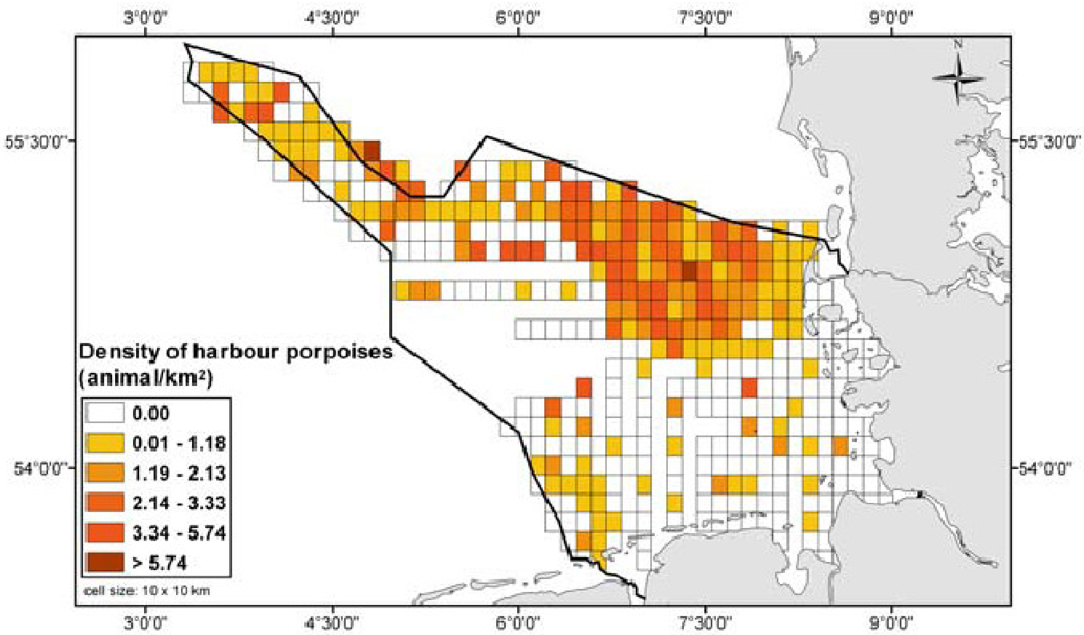


Figure 4.8. Map showing the density distribution of harbour porpoises in the German EEZ of the North Sea. Density is shown as animals per km² per cell (10x10 km). All flights conducted under good or moderate conditions from May to August 2002 and from May to August 2003 are shown. Map projection: Mercator.

Harbour Seals

Harbour seals, *Phoca vitulina*, are the most numerous of the two seal species of the Wadden Sea. They use the sand banks for resting, moulting, pupping and lactation during low tides. Since 1974, when hunting was strictly forbidden by the governments of The Netherlands, Germany and Denmark, the population increased continuously from 5,400 animals to around 15,000 seals in 1988, when an epizootic caused by the so called phocine distemper virus reduced the stock by approximately 60 % (Kennedy 1990; Reijnders et al. 1997). As of 2005, the population had increased to about 20,000 harbour seals in the Wadden Sea.

Possible impacts include reduced food supplies due to increased pressure from fisheries, and disturbance by the construction and operation of offshore wind farms. All offshore wind farms are scheduled to be built outside the Wadden Sea. Therefore, no conflict between seals and wind farms is expected, as the seal haul-out sites are outside the affected area.

However, seals spend around 80 % of their time in the water, in and outside the Wadden Sea. The data obtained by the MINOS Project showed that the animals leave their resting areas and headed more or less straight to distinct offshore areas, thereby reaching distances from land of approximately 100 km (Figure 4.9).

The main impact will probably be observed during the construction phase, from the noise of ramming and the resulting increased turbidity of the water, which may hinder seals and also their prey.

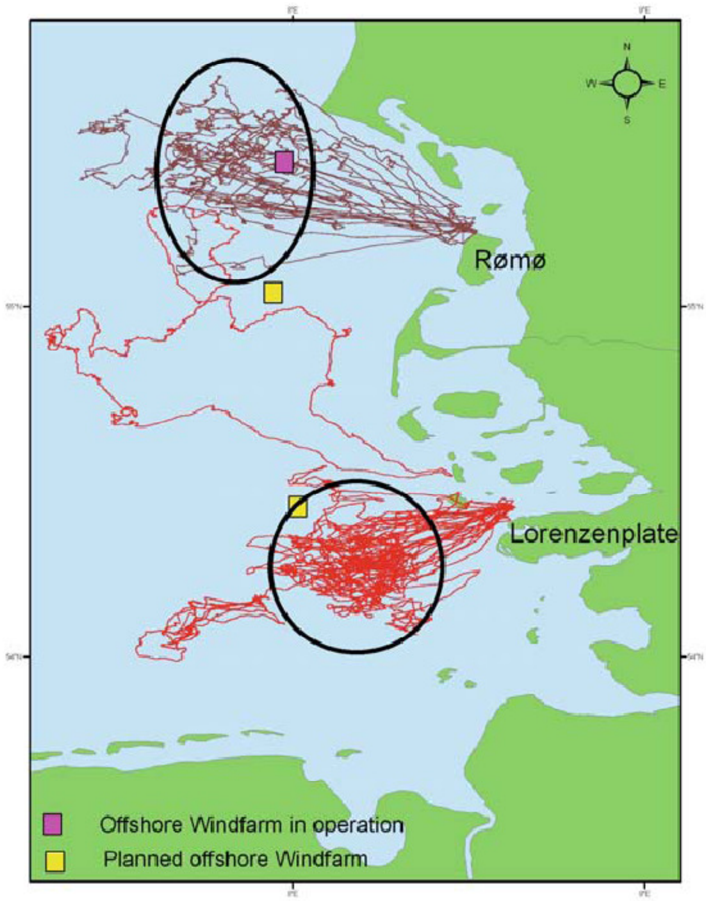


Figure 4.9. Foraging routes of harbour seals from the Lorenzenplate (based on three animals) and from Rømø (based on two animals).

During operation of these parks, the noise of rotating propellers emitted into the water could repel both seals and fish. An additional problem may occur when a series of wind farms is constructed, which could block migratory routes of seals from their haul-outs to foraging areas.

Conversely, wind farms could also be beneficial to seals, since fishing would be banned in these areas and new benthic organisms could settle there using the hard substrate of the pylons within this otherwise sandy area.

Conclusions

During installation of offshore windmills, the main impacts on both seals and harbour porpoises are the noise from ramming and similar building operations, increased ship traffic to and from the construction site, installation of cables, and greater turbidity of the water. These attendant circumstances of construction may also impair or deter fish, the seals' and porpoises' prey. The disturbances could result in avoiding the area mainly due to noise but as well as to lack of appropriate food.

During operation of offshore wind farms the windmills emit low-frequency noise into the water, and maintenance traffic adds to this noise pollution. It is undisputed that marine mammals are extraordinarily dependent on their hearing system, e.g. for intra-specific communication, foraging, and orientation. It is also beyond dispute that the installation of offshore windmills results in construction noise involving short-term activities of a few hours' duration, but these are repeated over a period of months at each wind farm site.

Another moot question is whether the animals will get used to the offshore wind farms or avoid them. Presumably, that is a species specific matter. However, offshore wind farms do not necessarily involve only disadvantages for marine mammals; rather, possible benefits due to expected reduction of fishing activities in offshore wind farm areas are also being discussed. These areas might provide a kind of refuge for benthic organisms, fish, and mammals, etc. The new hard substrates of the pylons could serve as artificial reefs, attracting new organisms – although displacing some of the original sandy bottom flora and fauna at the same time. If that led to a higher number of appropriate prey for marine mammals, positive effects might occur.

4.3.3. Fish

Introduction

The North Sea provides a habitat for approx. 250 fish species, and is among the most productive fishing waters in existence. In the North Sea, the distance from the coast seems to be the main factor determining the composition of the species community. The fish population is subject to heavy burdens which are primarily due to the increasing use pressure on these bodies of water. Intensive fishing is decimating the fish populations and destroying habitats.

The installation of wind parks could, through local alteration of habitat structures, potentially affect fish populations present in the area. At present a variety of possible impairments of the fish fauna are being discussed. Particularly low frequency sound can hurt fish physically, or induce flight reactions.

Species Composition

The German North Sea is an area in which habitat characteristics can change not only seasonally but also over a period of days. Within the German North Sea waters, 102 fish species were collected in 6,791 hauls over the last 50 years by different vessels and gears.

The five species most frequently present in the hauls were:

- ✓ the flatfishes dab (*Limanda limanda*) and plaice (*Pleuronectes platessa*),
- ✓ the gadoids whiting (*Merlangius merlangus*) and cod (*Gadus morhua*) and
- ✓ the pelagic clupeid herring (*Clupea harengus*), all of which were present in more than 50 % of the hauls.

All in all, 63 species of fish have been recorded in the potential wind park sites for the entire time interval 1982-2002. Pelagic clupeids, herring and sprat, appeared to be the most abundant species in almost all selected areas when judged by mean catch per hour. Of all demersal fish, dab, whiting and plaice were the most abundant species.

Conclusions

In the 2004 survey, the six most abundant species were responsible for 95 % of the total catch in numbers, a value which is common for North Sea areas. Therefore the diversity is low compared to other, especially tropical or subtropical areas. The total number of fish species found in the German North Sea varies between 102 and 189 species, given by the authors of the Red List on marine fishes of the German Wadden Sea and North Sea (Fricke et al, 1995). Some of the 87 additional species found in the latter list live in very shallow waters, others like big sharks are able to avoid the gears commonly used and yet others, like sun fish (*Mola mola*), stay at the surface, and thus outside the paths of the gears. Their rare attendance is of no importance to describe or assess the quality of the habitat.

In the German Bight it is mainly the depth and the distance from the coast that appears to have a major impact on the composition of the typical fish assemblage. Changes in the wind field may alter the boundaries (fronts) of these water masses (Dippner 1993), where, due to accumulation of plankton, fish may also aggregate.

4.3.4. Benthic Associations

Introduction

The benthic associations include all animals and plants living on the floor of the oceans and inland bodies of water, including both sessile organisms and animals living at the bottom of these waters which creep, walk or temporarily swim.

The conditions of life of the benthos are dependent on a number of abiotic factors, such as sediment conditions, salt content, light conditions, temperature and depth of water. In the German marine areas of the North and Baltic Seas, the benthic habitat is strongly subject to anthropogenic burdens.

The construction of offshore wind parks could, through structural installation over the seabed and shifting of sediments due to construction measures, affect the benthic communities or individual species. Non-mobile or hardly mobile species and suspension-feeding species (filterers) are particularly susceptible.

Species Composition

The underwater structure of the FINO 1 platform provides an artificial hard substrate which forms a new habitat for marine epifaunal organisms, which rarely occur in soft bottom communities, such as some sea anemones (Actinaria) and mussels (Bivalvia).

Only two weeks after the construction, the hydroid *Ectopleura larynx* almost completely covered the surface of the underwater structure. Hydroids are well known pioneer species in many marine environments, due to their adaptability to various substrates and their fast life cycles (Gili and Hughes 1995). In many cases, the establishment of the first species will determine the next arrivals: At FINO 1, a nudibranch (*Coryphella browni*) was the second inhabitant, feeding on the hydroid *Ectopleura larynx*. This initiated an ongoing succession process, with more and more species arriving.

After some time, the pile was in large parts densely covered by the amphipod *Jassa herdmani* (former syn. *J. falcata*), which builds dense tube mats accumulating to a large biomass. From the summer of 2004 onwards, the higher sections (up to approx. 5 m depth) of the piles were dominated by the blue mussel (*Mytilus edulis*), which provides a rich food source for the subsequently appearing predatory starfish (*Asterias rubens*).

Some species, like the hydroid *Ectopleura larynx,* not only appear early on empty grounds, but also reappear again every summer, settling even on the existing fauna. However, at other times, other species take over and became dominant at certain depths, giving rise to a highly dynamic pattern of succession.

Compared to natural hard substrates and coastal habitats, the species spectrum found to date on the piles shows rather low diversity. However, the present situation has not yet reached a steady "climax" state, and further arrivals are still expected.

Predators like the common starfish (*Asterias rubens*) and the swimming crab (*Liocarcinus holsatus*) roam the surface foraging for food. Near the bottom there are also some smaller edible crabs (*Cancer pagurus)* climbing the piles, while larger adult individuals are found on the ground around the piles.

Accumulation of Biomass

The blue mussel (*Mytilus edulis*) constitutes most of the biomass in the shallower areas of the piles, while the amphipod *Jassa herdmani* dominates in the deeper zones. A part of this biomass is constantly eroded by wave action or movements of mobile predators, and, together with the faeces of all organisms, sinks to the ground.

This enormous amount of biomass provides food sources not only for benthic organisms, but also for such higher predators as fish. Near the platform, large aggregations of horse mackerel (*Trachurus trachurus*) have been observed.

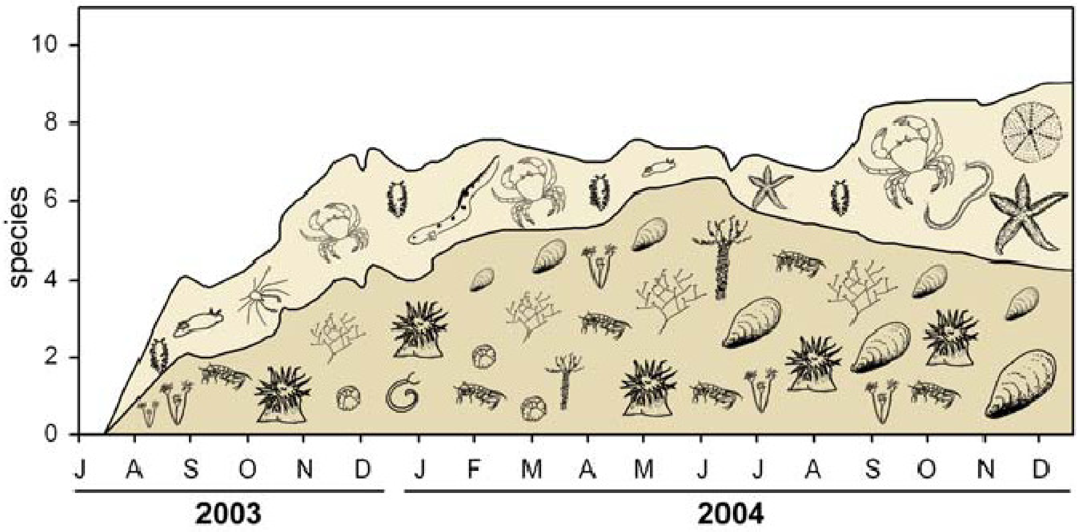


Figure 4.10. Temporal development of epifaunal species number on FINO 1. The lower area shows the mean number of mostly sessile species. The addition of mobile organisms sums up to the total number of species per photograph (approx. 0.04 m²)

Alterations of Sediments

The natural sea bottom in most areas proposed for offshore wind farms in the German Bight consists of soft sediments ranging from muddy fine sand to coarse sand. In the vicinity of hard substrates, modified hydrographic regimes alter sediment properties and hard substrate fauna influences the surrounding soft bottom fauna both directly and indirectly.

The construction of FINO 1 has changed the hydrographic regime in the direct surrounding of the platform, resulting in significant changes in local sediment composition. Artificial underwater structures can change the physical conditions in their surroundings, such as local current speeds and organic carbon contents, thereby creating altered sediment conditions (e.g.Davis et al. 1982, Ambrose and Anderson 1990).

Changes in Faunal Communities

The fauna in the direct vicinity of the platform was altered, most prominently at 1 m distance from the pile. This close to the platform, there was surely a direct influence of the construction works, causing a diminishment of the fauna; however the alterations of the sediments also influenced the ability of many species to colonise this area.

Many typical soft bottom inhabitants were absent or much less abundant around the platform. This particularly affected species which live burrowed in the ground as the bivalve *Tellina fabula* or the heart urchin *Echinocardium cordatum*, but also the Ophiuroids, which are normally quite abundant in such communities. Many polychaetes, which constitute a major component of typical soft bottom fauna, were found, if at all, only in very low densities in the vicinity of the platform, such as *Poecilochaetus serpens*, *Chaetozone setosa*, or such tube building species as *Spiophanes bombyx*.

However, a few species did reach higher densities around the piles than in the reference areas. Mobile predators, such as hermit crabs (*Pagurus bernhardus*), swimming crabs (*Liocarcinus holsatus*), some amphipods and carnivorous polychaetes, such as *Eunereis longissima*, appeared in larger numbers in nearby areas. The closure of a radius of 500 m to fisheries protected the area from bottom trawling, which is very intensive in this area.

Effect of Electromagnetic Fields on Marine Organisms

Artificial magnetic fields are unavoidable features of offshore wind farms in natural geomagnetic field environments. The electricity generated by the movement of the wind over the blades is transmitted by cables over long distances. Operating electric currents always produce magnetic fields.

All points on the earth's surface are characterised by the presence of a static geomagnetic field. In addition to the geomagnetic fields, marine benthic fauna could be subjected to artificial magnetic fields (Gill 2005), which, at a current of I=1,600 A, could produce a magnetic flux density of B=3.2 mT at a distance of 0.1 m, 1.0 mT at a distance of 0.3 m, and even at a distance of 6 m it is in the range of natural geomagnetic field, at about 50 µT.

It has been shown that externally applied magnetic fields could interact with biological systems to produce detectable changes. In the hydroid *Clava multicornis,* reproduction was faster at a magnetic intensity of 10 and 20 mT than in control and at 40 mT (Karlsen and Aristharkhov 1985). In *Mytilus edulis,* magnetic field action of 5.8, 8 and 80 mT leads to a 20 % decrease in hydration and 15 % decrease in amine nitrogen values (Aristharkhov et al. 1988).

However, recent studies indicate that the animals tested did not react when exposed to an artificial magnetic field. Static magnetic fields of submarine cables seem thus to have no clear influence on orientation, movement and physiology of the tested benthic animals.

Conclusions

A highly dynamic epifauna is expected to be settled on the underwater structure, reaching an as yet relatively low diversity, albeit with a high biomass. With its strong seasonal fluctuations, it produces a continuous export of biogenic material, which is hard to quantify at present. The lumps of biomass not only provides additional resources, but more importantly a different quality of food.

At the research platform FINO 1, the surrounding sediments as well as the soft bottom community have already experienced significant alterations. However, equilibrium has not been reached, and the final extension of this sphere of influence cannot yet be estimated definitively. For such a single structure, this effect may be seen as a restricted local phenomenon, but the proposed wind farms, with hundreds of similar structures, may cumulatively lead to considerable impacts.

The effects will also depend on the type of underwater structures, the materials used, and the question as to whether anti-fouling or scour protection is applied or not.

4.4. IDENTIFICATION AND VALUATION OF ENVIRONMENTAL IMPACTS

4.4.1. Qualitative Valoration

The main impacts, which the construction of the offshore wind energy installation could have on the environment, are described below:

Permanent habitat loss for sea birds

Wind farms can cause widespread avoidance of these areas by birds, resulting in a displacement effect. Particularly such for food-searching, disturbance-sensitive seabird species as red-throated diver and blackthroated diver, this displacement, or the fragmentation of coherent ecological units (e.g. resting and feeding areas), can cause permanent habitat loss. Given a lack of alternative habitats, this can directly affect population development.

Endangerment of bird migration due to bird strike

Immediate endangerment to bird migration exists due to the risk of collision with the turbines (bird strike). Particularly during unfavourable weather situations, species which migrate at the height of the effect of the turbines (0 - 150 m) can suffer considerable collision rates. This loss of individuals can have a negative effect on the overall population development at some species.

Endangerment of bird migration due to the barrier effect

A wind farm in the German Exclusive Economic Zone (EEZ) can have a barrier effect on migrating birds, forcing them into energy-consuming evasive action. These unintentional detours can lead either to direct loss of individuals, or reduce reproduction rates, and hence have a negative impact on the population development of some species.

Hearing damage to and/or displacement of marine mammals

With regard to marine mammals, the effects of noise are to be expected mainly during the construction phase. Especially during the ramming of the foundations, considerable acoustic emissions can be of great significance for marine mammals.

The noise immission during the construction period is not long-lasting, compared with the operational noise of the facilities, but for the species of mammals relevant in the North Sea area, it could lead to displacement or even to permanent damage (change in hearing thresholds, fatal injuries), depending on noise intensity and frequency range. Mother-calf groups are considered especially sensitive. Vibration of the turbine’s gear box and generator is guided downwards and radiated as sound from the tower wall (Figure 4.11).

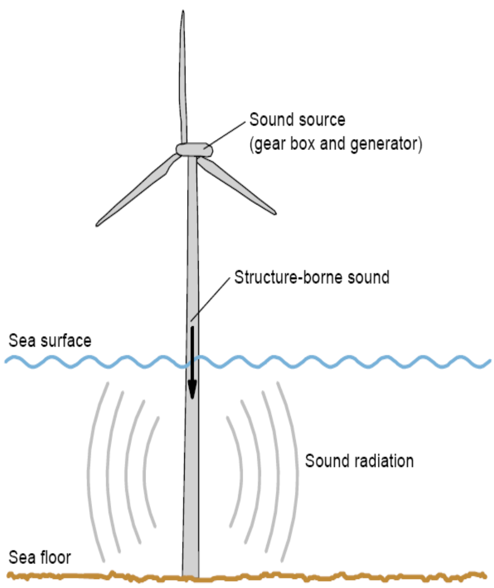


Figure 4.11. Mechanism of underwater noise generation by an offshore wind turbine.

Marine pollution due to ship collisions

Offshore wind farms are an obstacle to shipping, and therefore constitute a potential risk of accidents. Collisions of ships with wind farms could occur either with or without pollutant spills (oil, other pollutants), resulting in considerable effects on the entire ecosystem, including the coasts. There is a high risk potential of collision in the areas of traffic separation. The intensity of impairment of the marine environment due to ship collisions is independent of its location and the specific nature of environmental assets occurring there.

Impairment of the landscape

Even if the marine area of the EEZ does not border directly on the coast, it constitutes an essential component of the coastal landscape, due to its long-distance effects. Major areas of the North Sea coast and the offshore islands are used by tourists to a considerable degree, and a clear view of the sea is an important factor for all resorts along the coast.

The construction of wind farms introduces vertical structures into a space which is as a rule free of obstacles and characterised almost exclusively by horizontal structures. The installation of offshore wind farms can disrupt the tourist attractiveness of vacation sites and thus degrade the recreation experience to some degree.

4.4.2. Impact Assessment Criteria

For the valuation of impacts, a method based on the *"Leopold Matrix"* has been used, which evaluates the environmental factors that will be affected by actions during the project. These possible impacts are generated from matching the different environmental factors to the individual actions, as to during the construction phase, operation phase and decommissioning phase, which will be carried out. This assessment will take into account both on-site impacts as well as those which may affect adjacent areas of nature conservation value.

For this valuation of the impacts two characteristics have been considered:

- **Magnitude of the impact** (the first number that appears in each square), valuated in order to the impact intensity and severity.
- **Importance of the impact** (second number that appears), valuated in order to the impact extension and significance.

For both cases a scale of the 1 settles down (minimum value) to the 10 (maximum value). In addition, a sign, positive or negative is given (based on improving or making worse the state of the environmental factor). Impacts are assessed taking account of mitigation measures and consideration of positive influences.

Impacts have been expressed as:

- **Adverse**: detrimental or negative impacts to an environmental resource or receptor;
- **Beneficial**: advantageous or positive impact to an environmental resource or receptor; and,
- **Negligible**: no significant impacts to an environmental resource or receptor.

The global environmental impact importance will be measured through a formula that includes the following symbols

PARAMETER	VALUATION
SIGN	
Beneficial Impact	+
Detrimental Impact	-
INTENSITY (IN)	
Low	1
Average	2
High	4
Very high	8
Total	16
EXTENSION (EX)	
Precise	1
Partial	2
Extensive	4
Total	8
MOMENT (MO)	
Long term	1
Mid term	2
Immediate	4
PERSISTENCE (PE)	
Fleeting	1
Temporary	2
Permanent	4
REVERSIBILITY (RV)	
Short term	1
Mid term	2
Irreversible	4

The formula used to valuate the global importance of each action is as follows:

$$I = (+/-)\ (3\ IN + 2\ EX + MO + PE + RV)$$

This formula varies from +/- (0-76) and the global impacts will be included in one of the following three categories:

- ✓ **Minor**: slight, very short term or highly localised impacts of no significant consequence. (Its range will be from 0 to -15).
- ✓ **Moderate**: limited impact (by extent, duration or magnitude) which may nonetheless be considered significant in the context of the site and/or surroundings areas (its range will be from -16 to -35); or

- ✓ **Major**: considerable impact (by extent, duration or magnitude) of more than local significance or in breach of recognised acceptability, legislation, policy or standards.(Its range will be from -36 to -76)

In a similar way a classification for the positve impacts has been created. The principles to follow are the same as for the negative impacts, but in this case the impacts are classified in order to the bigger or smaller incidence degree, and not as much with respect to its effect as in the case of the negatives.

- ✓ **Reduced**: slight, very short term or highly localised positive impacts. Its range will be from 0 to 15.
- ✓ **Notable**: limited positive impact, which may nonetheless be considered significant in the context o the site and/or surroundings areas. Its range will be from 16 to 35.
- ✓ **High**: considerable positive impact of more than local significance. Its range will be from 36 to 76.

4.4.3. Matrix of Impacts Identification

The matrix of impacts identification (Figure 4.12) is generated from matching the different environmental factors to the individual actions As a result; the possible impacts will be identified.

4.4.4. Complex matrix cause-effect of valuation of Environmental Impacts.

The complex matrix cause-effect of valuation of environmental impacts is detailed in Figure 4.13. The cells coloured in yellow mean either adverse or beneficial impacts whilst the rest of the cells mean negligible impacts. The negligible impacts will not be valuated.

ACTIONS	
Construction phase	
Operational phase	
Decommissioning phase	
FACTORS	
Socio-economic	
Physical and Biological	

Table 4.4. Legend of colours 1.

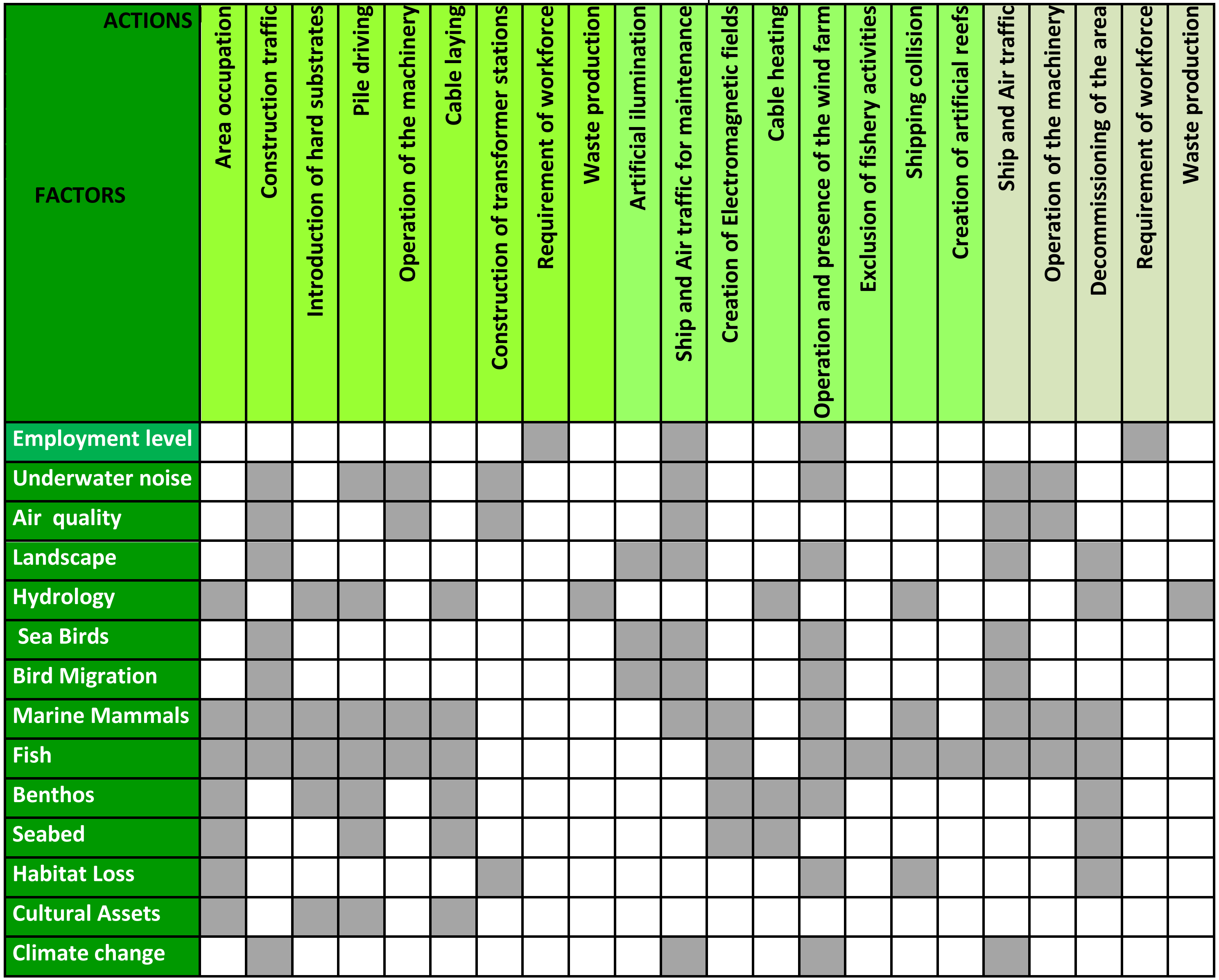


Figure 4.12. Matrix of impacts identification.

ACTIONS FACTORS	Area occupation	Construction traffic	Introduction of hard substrates	Pile driving	Operation of the machinery	Cable laying	Construction of transformer stations	Requirement of workforce	Waste production	Artificial illumination	Ship and Air traffic for maintenance	Creation of Electromagnetic fields	Cable heating	Operation and presence of the wind farm	Exclusion of fishery activities	Shipping collision	Creation of artificial reefs	Ship and Air traffic	Operation of the machinery	Decommissioning of the area	Requirement of workforce	Waste production
Employment level								+6/5			+5/6			+5/7							+6/5	
Underwater noise		4/4		7/5	7/5		4/4				4/4			8/7				4/4	7/5			
Air quality		3/3			5/4		3/4				3/3							3/3	5/4			
Landscape		3/3								7/6	4/4			8/6				3/3		+8/6		
Hydrology	5/4		5/4	5/4		5/4			6/6				6/6			4/6				+5/4		6/6
Sea Birds		3/4								7/6	5/4			8/4				3/4				
Bird Migration		3/4								7/6	5/4			8/7				3/4				
Marine Mammals	3/3	3/4	3/4	8/7	6/5	2/2					3/4	5/4		7/6		3/4		3/4	3/4	+7/6		
Fish	4/3	3/4	4/3	6/5	6/5	6/5						7/6		7/6	+7/6	4/6	+5/6	4/3	6/5	+7/6		
Benthos	3/3		3/4	6/5		5/5						5/4	6/5	4/4						3/3		
Seabed	3/3			5/6		5/6						5/4	6/5							3/3		
Habitat Loss	7/5						4/3							4/4		3/5				+7/5		
Cultural Assets	2/2		2/2	2/2		2/2																
Climate change		2/2									3/3			+9/7				2/2				

Figure 4.13. Complex Matrix cause-effect of valuation of environmental impacts.

4.4.5. Matrix of Importance of Environmental Impacts

The table with the valuation of global importance of the factors, resulting of using the global importance formula explained before, is shown below. As said previously, only adverse and beneficial impacts will be valuated.

TABLE OF VALUATION OF GLOBAL IMPORTANCE OF THE FACTORS					
FACTORS	FORMULA I =(+/-)(3 IN + 2 EX+ MO + PE + RV)		GLOBAL IMPORTANCE		
			PARTIAL	TOTAL	OUT OF +/- 76
Employment level	Requirement of workfoce (C)	I = +(3X4 + 2X2+2+ 2+2)	**22**	**78**	**20**
	Ship and air traffic for maintenance	I = +(3X2 + 2X1+1+4+4)	**17**		
	Operation and presence of the wind farm	I = +(3X2 + 2X1+1+4 +4)	**17**		
	Requirement of workfoce (D)	I = +(3X4 + 2X2+2+2 +2)	**22**		
Underwater noise	Pile driving	I = -(3X8 + 2X2+4+2 +1)	**-35**	**-110**	**-28**
	Operation of the machinery (C)	I = -(3X4 + 2X2+4+2 +1)	**-23**		
	Operation and presence of the wind farm	I = -(3X4 + 2X4+1+4 +4)	**-29**		
	Operation of the machinery (D)	I = -(3X4 + 2X2+4+2 +1)	**-23**		
Landscape	Artificial Ilumination	I = -(3X4 + 2X2+1+4 +4)	**-25**	**-25**	**-8**
	Operation and presence of the wind farm	I = -(3X8 + 2X2+1+4 +4)	**-37**		
	Decommissioning of the area	I = +(3X8 + 2X2+1+4 +4)	**37**		
Hydrology	Waste production (C)	I = -(3X2 + 2X2+4+2+1)	**-17**	**-91**	**-23**
	Cable heating	I = -(3X2 + 2X2+1+4 +4)	**-19**		
	Shipping collision	I = -(3X8 + 2X4+2+2 +2)	**-38**		
	Waste production (D)	I = -(3X2 + 2X2+4+2 +1)	**-17**		
Sea Birds	Artificial Ilumination	I = -(3X2 + 2X4+1+4 +4)	**-23**	**-64**	**-32**
	Operation and presence of the wind farm	I = -(3X8 + 2X4+1+4 +4)	**-41**		
Bird Migration	Artificial Ilumination	I = -(3X2 + 2X2+1+2 +4)	**-17**	**-40**	**-20**
	Operation and presence of the wind farm	I = -(3X4 + 2X2+1+2 +4)	**-23**		
Marine Mammals	Pile driving	I = -(3X4 + 2X2+4+2 +1)	**-23**	**-71**	**-24**
	Operation of the machinery (C)	I = -(3X4 + 2X2+4+2 +2)	**-24**		
	Operation of the machinery (D)	I = -(3X4 + 2X2+4+2 +2)	**-24**		

Table 4.5. Matrix of global importance-Factors

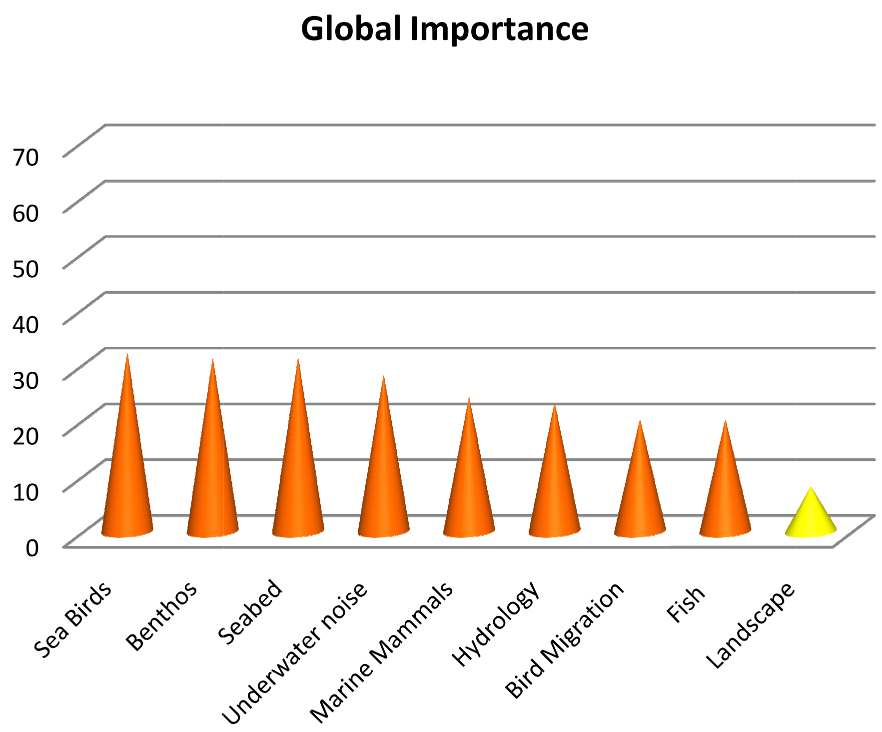
TABLE OF VALUATION OF GLOBAL IMPORTANCE OF THE FACTORS					
FACTORS	**FORMULA** **I =(+/-)(3 IN + 2 EX+ MO + PE + RV)**		**GLOBAL IMPORTANCE**		
			PARTIAL	**TOTAL**	**OUT OF +/- 76**
Fish	Pile driving	I = -(3X8 + 2X2+4+2 +1)	**-35**	**-180**	**-20**
	Operation of the machinery (C)	I = -(3X4 + 2X2+4+2 +2)	**-24**		
	Cable laying	I = -(3X4 + 2X4+1+4 +4)	**-29**		
	Creation of Electromagnetic fields	I = -(3X2 + 2X4+1+4 +4)	**-23**		
	Operation and presence of the wind farm	I = -(3X8 + 2X4+1+4 +4)	**-41**		
	Exclusion of fishery activities	I = +(3X2 + 2X1+1+4 +4)	**17**		
	Shipping collision	I = -(3X8 + 2X4+2+2 +2)	**-38**		
	Creation of artificial reefs	I = +(3X2 + 2X1+1+4 +4)	**17**		
	Operation of the machinery (D)	I = -(3X4 + 2X2+4+2 +2)	**-24**		
Benthos	Pile driving	I = -(3X8 + 2X2+4+2 +2)	**-36**	**-94**	**-31**
	Cable laying	I = -(3X4 + 2X4+1+4 +4)	**-29**		
	Cable heating	I = -(3X4 + 2X4+1+4 +4)	**-29**		
Seabed	Pile driving	I = -(3X8 + 2X2+4+2 +2)	**-36**	**-94**	**-31**
	Cable laying	I = -(3X4 + 2X4+1+4 +4)	**-29**		
	Cable heating	I = -(3X4 + 2X4+1+4 +4)	**-29**		
Habitat Loss	Area occupation	I = -(3X2 + 2X2+1+4 +4)	**-19**	**0**	**0**
	Decommissioning of the area	I = +(3X2 + 2X2+1+4 +4)	**19**		
Climate Change	Operation and presence of the wind farm	I = +(3X8 + 2X4+1+4 +4)	**41**	**41**	**41**

Table 4.5 (cont). Matrix of global importance-Factors

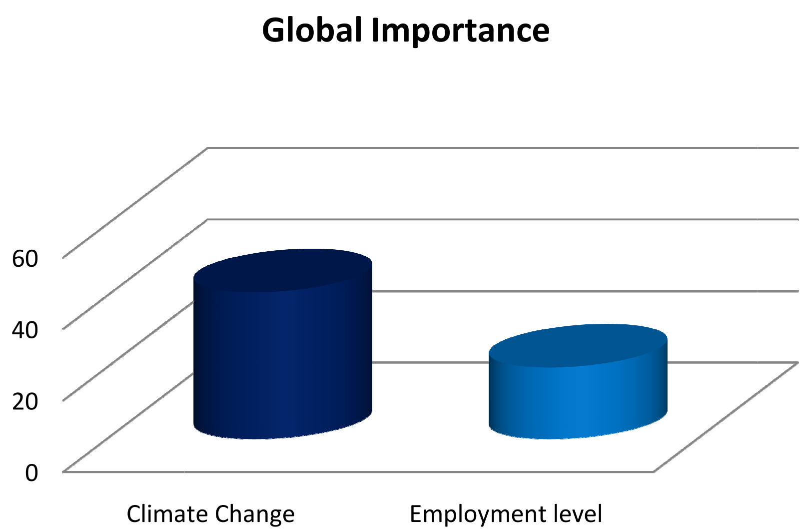
Adverse Impact		**Beneficial Impact**	
Minor	**- (0-15)**	***Reduced***	**+ (0-15)**
Moderate	**-(16-35)**	***Notable***	**+(16-35)**
Major	**-(36 – 76)**	***High***	**+(36 – 76)**

Table 4.5. Legend of colours 2.

Graphics 1 and 2 show the global impacts (adverse and beneficial) caused by the Offshore Wind Farm project on each factor.



Graphic 4.1. Adverse global impacts.



Graphic 4.2. Beneficial global impacts.

4.4.6. Interpretation of Results

Majority of the adverse impacts will occur during the construction and operational phase. The impacts related to the construction phase are temporary and result in a moderate impact on the environment. During the operational phase some moderate impacts on the fauna has been detected. The impact resulting of the presence and operation of the wind turbines on the landscape has been considered as a minor impact since the decommissioning phase has also been included as part of the environmental impact assessment process.

Mitigation measures would limit, avoid or offset the adverse environmental impacts that have been identified and where relevant, they would enhance the value of existing features.

On the other hand, two beneficial impacts have been found. One of them, the impact of the project on the Climate Change, has been valuated as a high impact whereas the second one, the impact of the offshore wind farm on the employment level has been considered as a notable impact.

The installation of the Offshore Wind Farm will produce new jobs during the three phases of its life cycle. In addition, the project will collaborate with the sustainable development trough the production of renewable energy and consequently it will help to reduce the carbon dioxide emissions.

It is therefore considered, that the proposed project will not result in either large scale or widespread environmental damage.

4.5. DOCUMENT OF PREVENTIVE AND MITIGATION MEASURES

4.5.1. Introduction

Offshore wind energy utilisation will play an essential role in the renewable's share of Germany's total electricity generation. The aim is for this utilisation to be environmentally and ecologically compatible.

The mitigation measures are fundamental to the EIA process. During the construction of wind farms measures should be taken to allow the greatest possible prevention and reduction of negative impacts on the living and non-living marine environment. Accompanying Ecological research to date has shown that technical mitigation measures can reduce impacts such as noise emissions, turbidity plumes or the development of electromagnetic fields.

4.5.2. Proposed Mitigation Measures

Four main mitigation measures (Table 4.6, 4.7, 4.8 and 4.9) have been proposed in order to prevent and reduce the negative impacts which have been found. These are as follows:

MEASURE 1: USE OF INTERNATIONALLY ACEPTED PRACTICE		
IDENTIFICATION OF THE PROPOSE MEASURE		
CLASIFICATION	**According to the impact recovery**	Possible measure
	According to the impact sign	Enhancing measure
	According to content of the Project affected	N/A
	According to its purpose	N/A
	According to the number of impacts on which it acts	N/A
	According to the severity of the impact	N/A
	According to its character	N/A
	According to the own place of application	N/A
OBJECTIVE	Prevention of accidents during construction.	
MEASURE DESCRIPTION	All the necessary protection measures will be taken for each type of the civil works involved. All construction and rehabilitation works should be carried out in accordance with health and safety regulations. Safety measures will be adopted, so as to protect the personnel involved in the construction. Public access to the construction sites will be restricted. Internationally accepted practice and existing regulations will be obeyed due to health and safety.	
MOMENT OF APPLICATION	During the construction phase.	
RESIDUAL IMPACTS	**Resulting residual impact**	None
	Impact generated by the own measurement	None

Table 4.6. Measure 1: Use of internationally accepted practice.

<table>
<tr><td colspan="4">MEASURE 2: WASTE MANAGEMENT</td></tr>
<tr><td colspan="4">IDENTIFICATION OF THE PROPOSE MEASURE</td></tr>
<tr><td rowspan="8">CLASIFICATION</td><td>According to the impact recovery</td><td colspan="2">Possible measure</td></tr>
<tr><td>According to the impact sign</td><td colspan="2">Protective measure</td></tr>
<tr><td>According to content of the Project affected</td><td colspan="2">Partial measure</td></tr>
<tr><td>According to its purpose</td><td colspan="2">Eliminating measure</td></tr>
<tr><td>According to the number of impacts on which it acts</td><td colspan="2">Multi-purpose measure</td></tr>
<tr><td>According to the severity of the impact</td><td colspan="2">Obligatory measure</td></tr>
<tr><td>According to its character</td><td colspan="2">Corrective measure</td></tr>
<tr><td>According to the own place of application</td><td colspan="2">Internal measure</td></tr>
<tr><td>OBJECTIVE</td><td colspan="3">Prevention of contamination of the marine environment.</td></tr>
<tr><td>MEASURE DESCRIPTION</td><td colspan="3">Offshore wind farm projects generate a variety of solid and liquid wastes. Some of these wastes are attributable to construction activities, while others are due to either human presence (sanitary wastes, food wastes) or generic industrial operations (wastepaper, scrap metal, used paints and solvents). In order to prevent the marine environment from getting contaminated through the discharge of wastes, the Recommended Guidelines for the Waste Management in the Offshore Industry will be followed.</td></tr>
<tr><td>MOMENT OF APPLICATION</td><td colspan="3">During and after the construction period.</td></tr>
<tr><td rowspan="2">RESIDUAL IMPACTS</td><td colspan="2">Resulting residual impact</td><td>None</td></tr>
<tr><td colspan="2">Impact generated by the own measurement</td><td>None</td></tr>
</table>

Table 4.7. Measure 2: Waste Management.

<table>
<tr><td colspan="4">MEASURE 3: PROTECTION OF BIRDS</td></tr>
<tr><td colspan="4">IDENTIFICATION OF THE PROPOSE MEASURE</td></tr>
<tr><td rowspan="8">CLASIFICATION</td><td>According to the impact recovery</td><td colspan="2">Possible measure</td></tr>
<tr><td>According to the impact sign</td><td colspan="2">Protective measure</td></tr>
<tr><td>According to content of the Project affected</td><td colspan="2">Total measure</td></tr>
<tr><td>According to its purpose</td><td colspan="2">Minimising measure</td></tr>
<tr><td>According to the number of impacts on which it acts</td><td colspan="2">Single-purpose measure</td></tr>
<tr><td>According to the severity of the impact</td><td colspan="2">Obligatory measure</td></tr>
<tr><td>According to its character</td><td colspan="2">Corrective measure</td></tr>
<tr><td>According to the own place of application</td><td colspan="2">Internal measure</td></tr>
<tr><td>OBJECTIVE</td><td colspan="3">To prevent sea birds from collision wherever possible.</td></tr>
<tr><td>MEASURE DESCRIPTION</td><td colspan="3">Abandonment of plans for wind farms in zones with dense migration, e.g. in nearshore areas or along “migration corridors”;
alignment of turbines in rows parallel to the main migratory direction;
several kilometre-wide free migration corridors between wind farms;
no construction of wind farms between e.g. resting and foraging areas;
shut-down of turbines at nights with bad weather/visibility and high migration intensity;
refraining from large-scale continuous illumination;
to make wind turbines generally more recognisable to birds.</td></tr>
<tr><td>MOMENT OF APPLICATION</td><td colspan="3">During and after the construction period.</td></tr>
<tr><td rowspan="2">RESIDUAL IMPACTS</td><td colspan="2">Resulting residual impact</td><td>Reduction of energy production</td></tr>
<tr><td colspan="2">Impact generated by the own measurement</td><td>None</td></tr>
</table>

Table 4.8. Measure 3: Protection of Birds.

MEASURE 4: UNDERWATER NOISE REDUCTION		
IDENTIFICATION OF THE PROPOSE MEASURE		
CLASIFICATION	According to the impact recovery	Possible measure
	According to the impact sign	Protective measure
	According to content of the Project affected	Partial measure
	According to its purpose	Minimising measure
	According to the number of impacts on which it acts	Multi-purpose measure
	According to the severity of the impact	Advisable measure
	According to its character	Corrective measure
	According to the own place of application	Internal measure
OBJECTIVE	To reduce the noise level during the operational phase.	
MEASURE DESCRIPTION	The noise impact cannot be mitigated during the construction, but it is only a short-term impact. However the underwater noise level during the operation phase can be reduced by installing large turbines. The larger the turbine, the lower the tooth mesh frequencies. In this way, radiation efficiency of surface wave declines towards low frequencies, while hearing thresholds increase.	
MOMENT OF APPLICATION	During the operational phase.	
RESIDUAL IMPACTS	Resulting residual impact	None
	Impact generated by the own measurement	None

Table 4.9. Measure 4: Underwater noise reduction.

4.6. ENVIRONMENTAL MONITORING PLAN

Due to the limited duration of studies to date, it is unknown whether long-term changes will occur or whether instead some species can become habituated. This underlines the importance of continued monitoring at existing wind farms at various locations.

The purpose of environmental monitoring is to understand the status of pollutants and impacts during the construction and operation phase, and to provide implementation of mitigation measures. The program is aimed at integrating environmental concerns into the design and implementation of the proposed Offshore Wind Farm Project. The monitoring plan supports:

- Site-specific environmental monitoring.
- Training of staff/ contractors involved in project implementation.
- Monitoring and evaluating of mitigation measures identified during site-specific inspections.
-

The proposed environmental monitoring plan is shown below (Table 10).

Issue	Monitoring items	Monitoring point	Monitoring frequency
Hydrology	Water level and flow, pressure, turbidity, temperature, conductivity, pH, etc…	Before construction During construction After construction	Continuous
	Analyses according to health regulations	Before construction During construction After construction	Public Health Institute (daily, monthly and annual)
Noise	Leq(dB)	Construction phase (machinery, transport)	Occasionally
		Operating phase (turbines, maintenance traffic)	Occasionally
Sea Birds	Biological productivy and mortality	Construction phase Operationalphase	Monthly sampling, for 5 years.
Marine Mammals	Biological productivy, hearing impairments and mortality	Construction phase Operationalphase	Monthly sampling, for 5 years.
Fish	Biological productivy, hearing impairments and mortality	Construction phase Operational phase	Monthly sampling, for 5 years.
Benthos	Biological productivy	Construction phase Operationalphase	Monthly sampling, for 5 years.

Table 4.10. Environmental Monitoring Plan.

4.7. SYNTHESIS DOCUMENT

INTRODUCTION DOCUMENT

Environmental Impact Study Identification

The project subject to an Environmental Impact Study is the construction and implementation of an Offshore Wind Farm in the North Sea, in the area "Northern Borkum", adjacent to the FINO 1 Research Platform. The project is located within the German Exclusive Economic Zone (EEZ) and the site comprises 13.738 km^2.

Environmental Impact Study Justification

Offshore wind farms are a renewable, but not entirely conflict-free form of power generation. Not only the effects on competing maritime uses, but also the marine environment must be taken into account in the authorisation of such wind farms. For the approval of offshore wind farms in the German Exclusive Economic Zone (EEZ), the EU's Environmental Impact Assessment (EIA) directives and, if NATURA 2000 areas are involved, the appropriate assessment according to the Habitat Directive, are legally stipulated.

Definition of Objectives

The final objective which the Study of Environmental Impact tries to obtain is to anticipate, to predict and to look into the possible consequences that the installation and later operation of the Offshore Wind Farm will have on the environment. And to establish the necessary preventive and remedial actions, in order to avoid and to eliminate those effects originated by the Offshore Wind Farm or to reduce them to acceptable levels.

Boundary of the Surroundings affected by the Project

Considering the characteristics of the construction and implementation of this Offshore Wind Farm in Germany, in the area Kriegers Flak, and the environment surrounding the location of the project, the area studied will be the German Bight of the North Sea.

Justification of the Project's Location

The area "Northern Borkum" is suitable for the use of wind energy, due to the fact that it shows comparatively low water depths; between 23 meters in the southeast and 33 meters in the north. Besides, the area shows an ecosystem with only low occurrence in protection-needed ways of life.

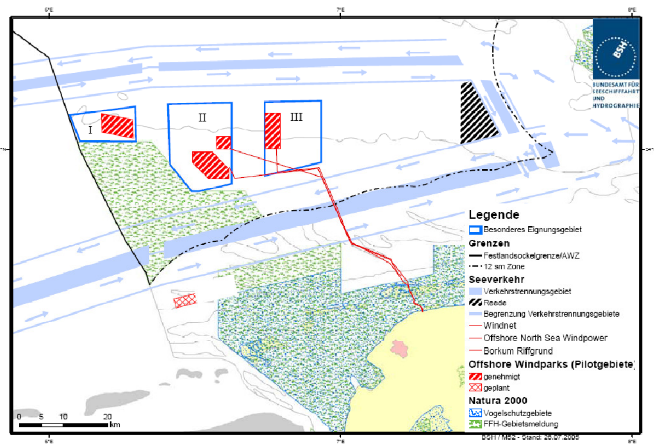


Figure 4.1. Subdivision and surrounding uses of "Northern Borkum" area.

In addition, the proposed area lies within sufficient distance to the recognized sea lanes essential to international navigation in this area: to the traffic division areas (VTG) German Bight Western Approach (GBWA) and Terschelling German Bight (TGB) as well as the Emsansteuerung. Figure 1 shows three different divisions of the “Northen Borkum” area. Our project is located within the partial surface II. As can be observed, the project does not lie within any Natura 2000 area.

Legal Framework

The main European Union Regulation, which applies to the Environmental Impact Assessment is the *Directive on the Assessment of the Effects of Certain Public and Private Projects on the Environment (85/337/EEC).*

In Germany, generating electricity by wind-powered plants is promoted by the *Renewable Energy Sources Act - EEG*. Under § 2 of the Marine Facilities Ordinance, wind farms in the Exclusive Economic Zone (EEZ)require the approval of the Federal Maritime and Hydrographic Agency (BSH). In order to get the license of an offshore wind farm in the EEZ the installations must not interfere with the use of recognised sea lanes essential to international navigation. In addition to the licensing of offshore wind farms, a permit must also be granted for laying the cable for the grid connection.

TECHNICAL DOCUMENT OF ANALYSIS OF THE PROJECT

Project Identification

- Location: **“Northern Borkum” area (North Sea)**
- Size of park: **42 turbines**
- Net Installed capacity: **150 MW**
- Production: **3500 Net Equivalent Hours (NEH)**
- Wind turbines:
  - Type: **Siemens SWT 3.6-107**
  - Height: **80 m**
  - Diametre: **107 m**
- Cable connection: **7 three-phase cables of 33kV**

Actions involved in the phases of the Project

Construction Phase	Operational Phase	Decommissioning Phase
▪ Land occupation	▪ Operation of the turbines	▪ Clearance of the area
▪ Introduction of hard substrata	▪ Presence of the wind farm	▪ Pile removing
▪ Pile driving for the foundations	▪ Waste production	▪ Waste production
▪ Cable laying	▪ Workforce requirement	
▪ Assembling of the wind turbines		
▪ Waste production		

PREOPERATIONAL ENVIRONMENT OF THE SURROUNDINGS OF THE PROJECT

Birds

Anually, more than ten million birds cross the North Sea, with considerable variation of migration intensity, time, altitude and species, depending on season and weather conditions.

Potentially two particular correlations of effects exist which could constitute endangerment to bird migration:

- ✓ the danger of collision with the turbines (bird strike), and
- ✓ the barrier effect, with forced avoidance and circumnavigation of the farms by the birds, resulting in an increased consumption of energy reserves.

Habitat loss can be expected for Red-throated Diver, Northern Gannet and Common Guillemot.

Marine Mammals

Three marine mammals' species are native to the German North Sea: the harbor porpoise *(Phocoena phocoena),* the harbor seal *(Phoca vitulina)* and the grey seal *(Halichoerus grypus).*

During installation of offshore windmills, the main impacts on both seals and harbour porpoises are the noise from ramming and similar building operations, increased ship traffic to and from the construction site, installation of cables, and greater turbidity of the water. During operation of offshore wind farms the windmills emit low-frequency noise into the water, and maintenance traffic adds to this noise pollution.

Fish

The North Sea provides a habitat for approx. 250 fish species, and is among the most productive fishing waters in existence. The five species most frequently present are: the flatfishes dab (*Limanda limanda*) and plaice (*Pleuronectes platessa*), the gadoids whiting (*Merlangius merlangus*) and cod (*Gadus morhua*) and the pelagic clupeid herring (*Clupea harengus*).The main impacts, which are expected on these fish communities, are the barrier effect caused by the windmills, the damages due to the construction activities and the exclusion of fisheries activities (beneficial impact).

Benthic Associations

The conditions of life of the benthos are dependent on a number of abiotic factors, such as sediment conditions, salt content, light conditions, temperature and depth of water. Compared to natural hard substrates and coastal habitats, the species spectrum found to date on the piles shows rather low diversity. However, the present situation has not yet reached a steady "climax" state, and further arrivals are still expected.

IDENTIFICATION AND VALUATION OF ENVIRONMENTAL IMPACTS

Qualitative Valoration

The main impacts, which the construction of the offshore wind energy installation could have on the environment, are described below:

- ✓ Permanent habitat loss for sea birds
- ✓ Endangerment of bird migration due to bird strike
- ✓ Endangerment of bird migration due to the barrier effect
- ✓ Hearing damage to and/or displacement of marine mammals
- ✓ Marine pollution due to ship collisions
- ✓ Impairment of the landscape

Impact Assessment Criteria

For the valuation of impacts, a method based on the *"Leopold Matrix"* has been used, which evaluates the environmental factors that will be affected by actions during the project. The matrix of impacts identification is generated from matching the different environmental factors to the individual actions, as to during the construction phase, the operation phase and the decommissioning phase which will be carried out. The Complex matrix cause-effect will assign two numbers to each detected impact. The first one referring to the magnitude of the impact and the second one referring to the importance of the impact.

Impacts will be expressed as adverse, beneficial or negligible and the global environmental impact importance will be measured through a formula which includes extension, intensity, moment, persistence and reversibility of the impacts.

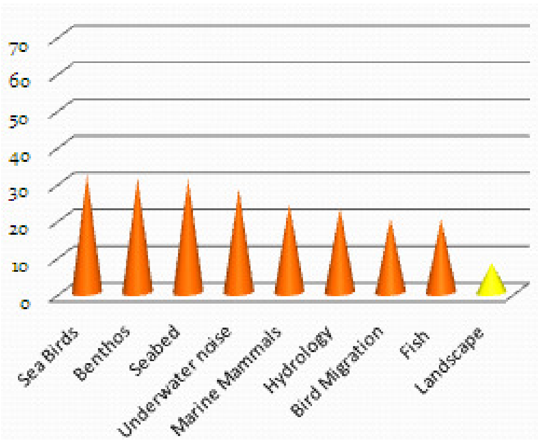
Finally, the global importance of the factors will be classified as minor, moderate or major ,for the beneficial impacts, and as reduced, notable and high for the adverse impacts.

Interpretation of Results

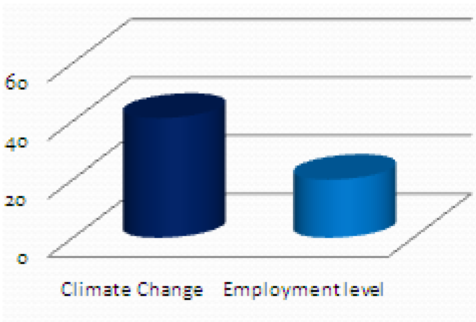
Majority of the adverse impacts will occur during the construction and operational phase. The impacts related to the construction phase are temporary and result in a moderate impact on the environment. During the operational phase some moderate impacts on the fauna has been detected. The impact resulting of the presence and operation of the wind turbines on the landscape has been considered as a minor impact since the decommissioning phase has also been included as part of the environmental impact assessment process.

On the other hand, two beneficial impacts have been found. One of them, the impact of the project on the Climate Change, has been valuated as a high impact whereas the second one, the impact of the offshore wind farm on the employment level has been considered as a notable impact.

It is therefore considered, that the proposed project will not result in either large scale or widespread environmental damage.



Graphic 1. Adverse Global Impacts



Graphic 2. Beneficial Global Impacts

DOCUMENT OF PREVENTIVE AND MITIGATION MEASURES

Mitigation measures would limit, avoid or offset the adverse environmental impacts that have been identified and where relevant, they would enhance the value of existing features. Four main mitigation measures have been proposed. These are as follows:

- *Use of internationally accepted practice* in order to comply with the Health and Safety Regulations;
- *Waste management*, following the "Recommended Guidelines for the Waste Management in the Offshore Industry";
- *Protection of birds*, by abandoning plans for wind farms in zones with dense migration and by making wind turbines generally more recognizable to birds;
- *Underwater noise reduction*, by installing large turbines.

ENVIRONMENTAL MONITORING PLAN

Due to the limited duration of studies to date, it is not known whether long-term changes will occur or whether instead some species can become habituated. This underlines the importance of continued monitoring at existing wind farms at various locations.

The proposed environmental monitoring plan includes monitoring items to control the hydrology, noise, sea birds, marine mammals, fish and benthos.

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5. Viability Analysis

CONTENTS

5.1. INTRODUCTION

In order to assess the viability of a project, two main aspects need to be evaluated:

- the impact of the project on the society and
- the economic viability of the project.

Regarding the first aspect, a justification of the need of the Project is required. Such justification should be based on a local, national and international development of the society. This first point it is widely justified since the electricity is a primary need and the current methods of production are very polluting. Therefore the construction of the Offshore Wind Farm in the North Sea would increase the electric power of Germany at the same time that would improve the environmental quality of the country.

In relation to the second aspect, a study of the economic profitability of the project for the shareholders must be done. Independently of how interesting the project results are, the project has to be profitable for the shareholders; understanding as profitability the capital gain which will be required by our financing sources according to the risk level of the put into operation of the project.

The object of the present document is to calculate the economic profitability of the installation of the Offshore Wind Farm in the North Sea. The process of calculating the mentioned profitability is complex and its result is subjective due to the wide number of hypothesis that need to be assumed. The greater the degree of working out of each stages of the project, the greater the accuracy of the final result.

5.2. DISCOUNT CASH FLOW METHOD

Shareholders are willing to put resources in a project today with the condition of recovering them in the future together with an additional profit.

There are several methods for evaluating the profitability of a project. However, the most internationally accepted one is the Discount Cash Flow (DCF) Method. This method is defined as the total present value (PV) of a time series of cash flows. It is a standard method for using the time value of money to appraise long-term projects. It also measures the excess or shortfall of cash flows, in present value terms, once financing charges are met (Source: Wikipedia).

Its mathematical expression is as follows: $$NPV = -R_0 + \sum_{t=0}^{t} \frac{Rt}{(1+i)^t}$$

Where

t- the time of the cash flow
i- the discount rate
Rt- the net cash flow (the amount of cash, inflow minus outflow) at time t (R_0 is commonly placed to the left of the sum to emphasize its role as (minus the) investment.

The rule of the Net Present Value can be considered as the beginning of the wealth conservation and its potential to create more wealth. The maximum value of a project in order to conserve the present potential wealth is the Present Value of all the amounts of money which this one will produce in the future.

The advantage of the Present Value lies in its capacity to collect all the elements related to the value of a project whereas the rest of methods omit them. Its disadvantage is that it is needed to develop many hypotheses for this purpose. In first place, the future behaviour of its operation needs to be supposed in order to establish how, how much and when this will create wealth. In second place, the maximum duration of the project has to be delimited. And last it is needed to do forecasts about the inflation, interest rates and risks of the project in order to choose the most appropriate discount rate.

In conclusion, it is a powerful formula for the calculation of the value of a project, but difficulties can be found to set its components *R, t* and *i*.

5.2.1. Analysis of the initial investment R_0

For the calculation of the initial investment we need to estimate the total cost of the offshore wind farm construction. We will include all the expenses from the construction phase to the put into operation of the wind farm once the project has been finished. Note well that due to the duration of the period lasted between the previous studies and the finishing of the construction of a project of such magnitude and as consequence of the high costs, the expenses would be divided up into the years and therefore being them affected by the discount rate. However, for simplicity reasons, we will consider for our project the initial investment divided up into the first two years.

5.2.2. Analysis of the duration of the project *t*

In order to get a precise valuation of the profitability of the Project we must establish its duration, this means the number of years which the Project will produce incomes for the shareholders.

The length of the project can be very variable. There are projects where the duration is few months whereas others last forever. For our project we will apply the duration which has been supposed for other German offshore wind farms. This means a useful life of 20 years. This is an assumption accepted a priori and therefore we consider the duration of the wind farm of 20 years, after which the installation will be decommissioned.

5.2.3. Analysis of the value of the initial investment *I*

The value of the initial investment is the initial amount, which the investors will have to invest in order to execute the process of construction of the offshore wind farm in Germany (North Sea).

This investment includes all the costs associated with previous studies, consultancy work, construction materials, machinery, workforce, technology, etc.

5.2.4. Analysis of the cash flows and terminal value for the various economic scenarios

The concept of cash flow refers to the flows generated by the operative activities of the project and which are available to be distributed between the investors after the needs have been met.

In the case of the project not having debts, it is possible to think of the cash flows of the project as the funds after tax corresponding to the shareholders. In order to deem the cash flows of this project, the method below will be followed:

(+/-) net profit
(+) interest paid
(+) Depreciation, amortization and accruals
(-) investment in fixed assets
(-) increase in NOF
(=) Free Cash-Flow

5.2.5. Analysis of the discount rate

Investors ask the Project for profitability, which is at least equivalent to the one which they could obtain with other investment with similar risk. Each series of flows must be updated to the corresponding rate. In this way the project flows must be updated at a rate that shows the cost of all the investors as a whole. The mentioned rate is the capital Weight Average Cost of Capital (WACC).

The debt cash flows are discounted at the interest rate of the debt whereas the capital cash flows, those who belong to the shareholders, must be discounted at the Internal Rate of Return (IRR) required by them.

5.3. INITIAL ASSUMPTIONS

5.3.1. Operative Assumptions

The operative assumptions are listed in the following table:

OPERATING DRIVERS	
Windfarm Region	**Northern Borkum**
Country	**Germany**
Start of Operations Date (Year)	**2010**
Success (%)	**100%**
Ownership (%)	**100%**
Net Installed Capacity (MW)	**150.0**
Capex (€ MM / MW)[22]	**2.8**
% of Investment in year 1[23]	**60%**
Hours (h)	**3500**
Feed in Tariff Years Initial Period (€/MWh)[24]	**150.0**
Initial Period (Year)	**12**
Pool+ Green Certificates Years thereafter(€/MWh)[2]	**100.0**
Tax Rate (%)[26]	**31.5%**
Useful Life (Year)	**20**
O&M Costs in Year 1 (€ / MWh)[27]	**20.0**
O&M Warranty Period Correction Factor (%)[28]	**60%**
O&M Warranty Period (Years)	**3.0**
Days of Acc. Receivable	**60**
Days of Acc. Payable	**30**

Table 5.1. Operative Assumptions for the Offshore Wind Farm.

5.3.2. Financial Assumptions

The financial hypotheses refer to the equity, debt and cost of the debt. For this project the following numbers will be assumed.

[22] Source: Carbon Trust Report.
[23] The percentage of investment for the first year has been assumed as 60% since we consider that the project will not be completely finished during the first year.
[24] In Germany, an initial tariff of 15 cents/kWh will be paid for a period of 12 years (Source: GWEC).
[25] A price of 10 cents/kWh has been assumed to be paid for the remaining 8 years of the project (Source: market estimates).
[26] Source: KPMG Report.
[27] Source: Market estimates.
[28] The O&M Warranty Period and the O&M Warranty Period Correction Factor refer to the fact that during the first 3 years, the maintenance costs will be the 60% of the future maintenance costs.

FINANCING DRIVERS	
Cost of Debt [29](%)	**7.1%**
Cost of Equity [30](%)	**14%**
Leverage (%)	**70%**
Loan life (years)	**15**
Tail [31](years)	**2**
Initial Debt (€ MM)	**294.0**

Table 5.2. Financial Assumptions for the Offshore Wind Farm.

5.3.3. Valuation Drivers

VALUATION DRIVERS	
Valuation Date	**6/21/2009**
WACC[32] (%)	**7.6%**
Terminal Value (pre-capitalization) (€ MM)	**0.0**
Decommissioning (% Initial Capex)	**5%**

Table 5.3. Valuation Assumptions.

5.4. FINANCIAL MODEL OF THE OFFSHORE WIND FARM

5.4.1. Investment

5.4.1.1. Economic Aspects defined by the University of Santander

- Offshore wind farms are likely to be larger than those on shore as the economies of scale in offshore projects are more significant.

- For the offshore wind farms, the installation and maintenance costs are sensibly higher than those estimated for the onshore wind farms. The costs are approximately 1.5-2 times the onshore costs, although a gradual reduction has been observed.

- Offshore parks require a greater investment than the parks installed onshore, mainly due to the foundations and electricity grid connection costs.

- Currently, there are not absolute values available for the deemed cost of this type of project since the existing data is based on the estimations of several offshore wind with different installation conditions.

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[29] 10Year Spanish Bond + 300 bps
[30] Source: Market estimates.
[31] A *tail* of 2 years means that we will not start paying the loan until the second year.
[32] Implied WACC from base case financing assumptions.

- Generally, the installation cost of the parks constructed up to date, have diminished from 2,200.00 €/kW (first Danish offshore wind farm) to 1,650.00 €/kW (cost of the Horns Rev, constructed in 2002). Table 5.4 shows the specific costs of investment for different offshore wind farms.

Wind Farm	Start of operations	Country	Net installed capacity (MW)	Investment (M€)	Cost (M€/MW)
Sheltered waters and/or small projects					
Vindeby	1992	Denmark	5	10.3	2.1
Lely	1994	Netherlands	2	4.5	2.3
Tuno Knob	1995	Denmark	5	10.4	2.1
Dronten	1996	Netherlands	11	20.5	1.2
Gotland	1997	Sweden	3	4.7	1.9
Utgrunden	2000	Sweden	11	13.9	1.4
Blyth Harbour	2000	UK	4	6.3	1.6
Middelgrunden	2001	Denmark	40	51.3	1.3
Samso	2003	Denmark	23	35	1.5
First near shore wind farms, shallow waters					
Hons Rev	2002	Denmark	160	300.0	1.9
Nysted	2003	Denmark	158	268.8	1.7
North Hoyle	2003	UK	60	105.7	1.8
Scroby Sands	2004	UK	60	107.1	1.8

Table 5.4. Investment cost of the different offshore wind farms in operation.

5.4.1.2. Cost of the different components.

a) Wind Turbines

The costs of the offshore wind turbines represent the 45-59% of the total cost of the installation whereas onshore energy systems represent the 70-80%.

The cost range for wind energy systems larger than 300 kW is as follows:

- 300 kW- 1MW: 650-759 €/kW.
- 1 MW- 2MW: 750 – 800 €/kW.
- 2MW- 3MW: 800 – 900 €/kW.
- 4MW – 5MW: 900-1100 €/kW. There are uncertainties since they are currently being developed.

b) Foundations

Foundations can represent up to the 30% of the total cost. Considering a deepness of 28 m and a monopile foundations, the costs vary from 300 to 400 k€/foundation, depending on the sea and the seabed conditions.

c) Electricity grid connection

The electricity grid connection of an offshore wind farm could represent up to 25% of the total cost of the park. This percentage is much greater than the onshore wind farms. This cost will depend on the distance to the shore, the voltage evacuated and the need of transformation station on the sea.

d) Maintenance

The maintenance operations of the offshore wind parks are more complex and expensive than the equivalent activities for the onshore wind farms. In some cases it will not be possible to access to the location of the wind energy systems due to the marine conditions, wind and poor visibility.

There are three tendencies in the estimation of the maintenance annual costs for the offshore wind farms. Due to the lack of previous information, none of these theories can be more reliable than the rest. The mentioned theories are as follows:

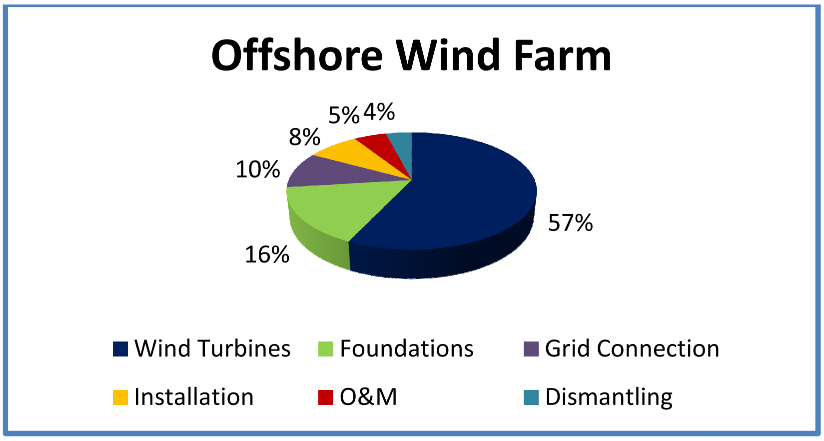
- According to Garrad Hassan, the O&M costs of the offshore wind farms installed in The UK will be proportional to the number of wind energy generators at the rate of £70.000 per unit.

- The O&M annual costs will be calculated either as 30.000,00 € per MW installed plus 0.06 c€ per kWh generated or according only to the energy generated at the rate of 1.2-1.5 c€ per kWh.

- The total O&M costs offshore will be considered as an annual provision of 2-3% of the initial investment.

e) Summary

The installation of large scale wind farms and the use of wind turbines of big power, reduce the cost per kW installed. Graphic 5.1 (Sources: Lako 2002; Carbon Trust Marine Technology Accelerator; Junginger and Faaij 2004; Junginger 2005) show the weight of the different average costs for the installation of an offshore and wind farm. This graphic highlights the relative weight of the foundations and the electricity grid connection costs of the offshore wind farms.



Graphic 5.1. Average costs for the installation of an offshore wind farm. Note: Grid Connection costs include substations (HVDC, Offshore AC). Onshore AC substation is to be paid by the network operator.

5.4.1.3. Investment Calculation

Based on the previous information, and the results shown in the Carbon Trust Report: "Offshore wind power: big challenge, big opportunity", where a capex is given according to the depth and distance from shore, a ratio of **2.8 M€/MW** has been considered for the estimation of the total investment. The results of this estimation are shown in Table 5.5.

CONSTRUCTION COSTS	
Wind Turbines	243,600,000 €
Foundations	67,200,000 €
Grid Connection	42,000,000 €
Installation	33,600,000 €
O&M	21,000,000 €
Dismantling	12,600,000 €
TOTAL	**420,000,000 €**

Table 5.5. Construction costs for the FINO Offshore Wind Farm.

Therefore, the Project will have an initial investment of **420,000,000 €.**

5.4.2. Free Cash Flows

5.4.2.1. Income

Grid operators are obliged to feed-in electricity produced from renewable energy and buy it at a fixed price within their supply area. Furthermore, the new EEG requires that grid operators not only extend the grid, but also that they optimize and enhance the existing grid. Failure to comply with this can lead to claims for damages by anyone willing but unable to feed-in. In addition, a bonus of 0.5 cent/kWh for improved grid compatibility (system service bonus) was introduced for new turbines (Source: GWEC).

The income created by the wind farm will come from the sale of the electricity produced. The tariff for offshore wind energy has been increased to 13 cents€/kWh plus an additional 'sprinter bonus' of 2 cents€/kWh for projects which will come into operation before the end of 2015. The initial 15 cents€/kWh will be paid for a period of 12 years. Thereafter, the tariff will decrease to 3.5 cents€/kWh. Given that wholesale electricity prices are expected to exceed 3.5 cents€/kWh at that time and the fact that this tariff is clearly insufficient, not even covering the operational expenses, the idea is that offshore wind power will be sold directly into the electricity and green certificates markets rather than continuing to rely on feed-in tariffs after 12 years of operation. A price of 6.3 cents€/kWh is expected for the electric market whereas a price of 2.7cents€/kWh has been assumed for the green certificates market (Source: market estimates). Therefore, the assumption taken is that after the 12 year initial period, the 3.5 cents/kWh tariff will be refused and an income of 10 cents/kwh will be obtained.

Nowadays, projects are under a strong researching and learning component. In addition the proposed scheme avoids income coming from direct finance to the development and construction of the project.

5.4.2.2. Operational Expenses

The operational expenses include all the negative cash flows which the project usually requires to work. These expenses refer mainly to the salaries for the employees and the O&M costs.

Operational expenses are approximately **20 € per MWh generated** (Source: Market estimates).

5.4.2.3 Depreciation and Amortization (D & A)

The wind farm has been considered as a fix asset during the 20 year duration of the project. Considering the technology of a wind farm, it has been chosen the digit numbers method to calculate the depreciation. This method allows an increasing or decreasing amortization. In our project, the amortization decreases since the wind energy generators will lose its value as the technology progresses. Based on the mentioned method, the following amount will be depreciated each year:

Year	1	2	...	20
D&A	$\frac{20}{addition(1:20)}$	$\frac{19}{addition(1:20)}$	...	$\frac{1}{addition(1:20)}$

5.4.2.4. Taxes

The taxes to be paid in the case of German are of **31.5%** of the annual incomes of the wind farm (Source: KPMG).

5.4.2.5. Weighted Average Cost of Capital (WACC) or Discount rate

For the Project valuation, the discount rate is intuitively the price that the moneylenders will invest in the construction of the project. This price only depends on the risk of the project and the equity and debt proportion.

In order to calculate the discount rate we must compare our project to other projects which have a similar risk. The discount rate considered is calculated below. This value will vary with the years depending on the development of the dealership and construction of the first farms.

$$\textbf{WACC} = \left[Ke \times \frac{\text{Equity}}{(\text{Equity+Debt})}\right] + \left[Kd \times (1-T) \times \frac{\text{Debt}}{(\text{Equity+Debt})}\right]$$

$$\text{WACC} = \left[0.14 \times \frac{0.3}{(0.3+0.7)}\right] + \left[0.071 \times (1-0.315) \times \frac{0.7}{(0.3+0.7)}\right] = \mathbf{7.6\%}$$

The first step when deciding on an investment is to check if the unlevered IRR obtained is greater than the WACC. For that purpose we will use the WACC calculated above.

5.4.3. Net Present Value

By discounting the cash flows, the net present value obtained is (see Appendix 2):

***VNP*=76,600,000.00**

5.4.4. Internal Rate of Return

Given a collection of pairs (time, cash flow) involved in project, the IRR follows from the NPV as a function of the rate of return. A rate of return for which this function is zero is an internal rate of return.

Given the (period, cash flow) pairs (*n, Cn*) where *n* is a positive integer, the total number of periods *N*, and the NPV, the IFF is given by r in the following formula:

$$\mathrm{NPV} = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n} = 0$$

The internal rate of return of the project or unlevered IRR is **11%** (see Appendix 2). This value means that the project will be financially viable as long as we get a financing cost lower than 11%.

However, the levered IRR, considering a leverage of 70% is of **21.1%** (see Appendix 2). This means that the project will be viable as long as the cost of equity is lower than 21.1%.

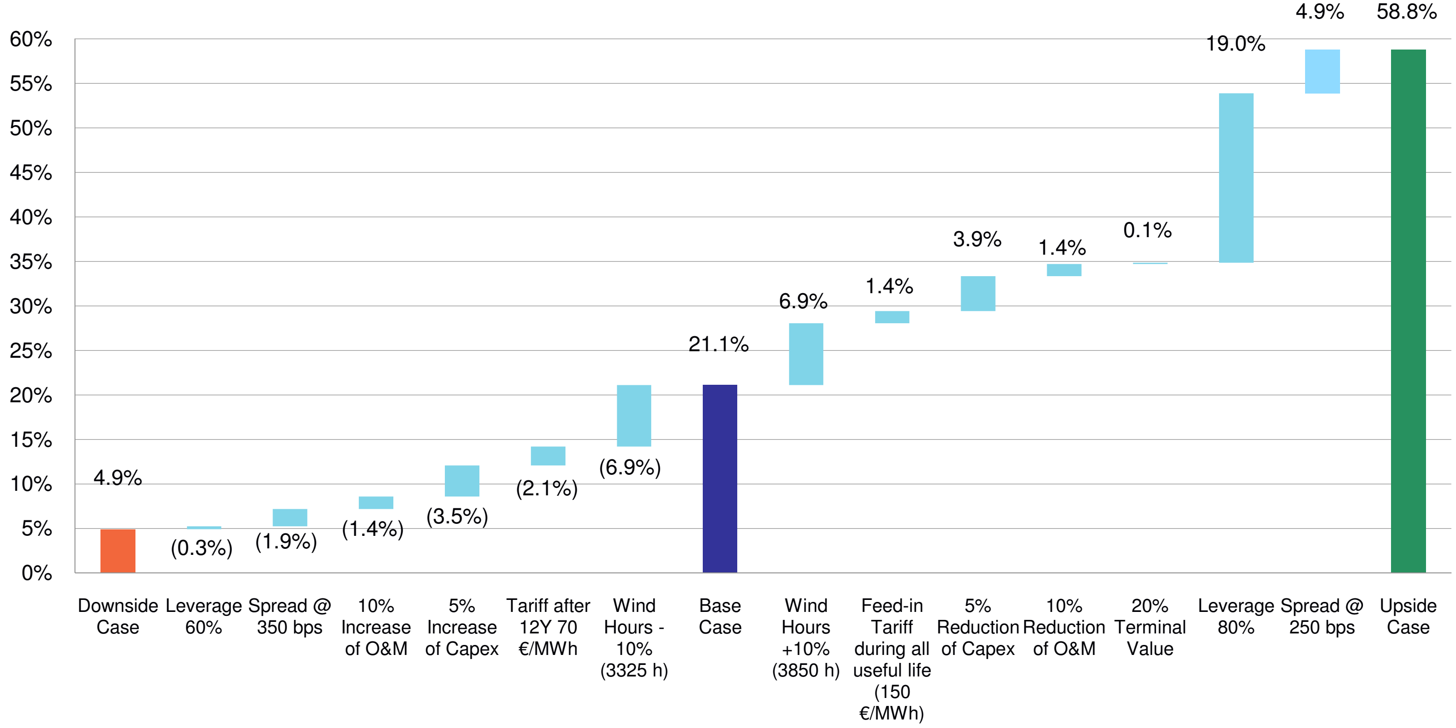
5.4.5. Payback Period

The payback period for our project is **8.5** years. It has been calculated by using the following expression:

$$\textbf{Payback Period} = \text{Year before recovery} + \frac{\text{Uncovered cost at starting of the year}}{\text{Cash flow during the year}}$$

5.5. SENSITIVITY ANALYSIS

5.5.1. Sensitivity Analysis to Shareholder's Return[33]



This sensitivity anlalysis has been made using the levered IRR in order to include the financial structure of the company as part of the analysis.

The waterfall chart shows how the initial levered IRR[34] (21.1%) is increased and decreased by a series of intermediate values, leading to a final bullish value and a final bearish value.

As can be observed the wind hours, the capex, the leverage and the cost of debt (these last two, when bullish scenarios are considered) seem to be the drivers leading to higher IRR marginal variations.

Graphic 5.2. Waterfall Chart- Sensitivity Analysis to Shareholders' Return.

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[33] Assuming a consecutive sequence of scenarios.
[34] Assuming a leverage of 70%.

5.5.1. Sensitivity Analysis of Unlevered and Levered IRR

A negative and positive deviation of (+/-) 5% and (+/-) 10% has been analyzed in order to assess the sensitivity of the results.

Sensitivity Analysis of Unlevered IRR

Unlevered IRR (%)

		NEH (Hours)				
		-10%	-5%	3,500	+5%	+10%
Capex (€ MM)	+10%	7.9%	8.7%	9.5%	10.3%	11.0%
	+5%	8.6%	9.4%	10.2%	11.0%	11.9%
	2.8	9.3%	10.2%	11.0%	11.9%	12.7%
	-5%	10.2%	11.0%	11.9%	12.8%	13.7%
	-10%	11.0%	12.0%	12.9%	13.8%	14.8%

Unlevered IRR (%)

		NEH (Hours)				
		-10%	-5%	3,500	+5%	+10%
Pool Price (€/MWh)	+10%	9.6%	10.5%	11.3%	12.2%	13.0%
	+5%	9.5%	10.3%	11.2%	12.0%	12.9%
	100.0	9.3%	10.2%	11.0%	11.9%	12.7%
	-5%	9.2%	10.0%	10.9%	11.8%	12.6%
	-10%	9.0%	9.9%	10.8%	11.6%	12.5%

Sensitivity Analysis of Levered IRR

Levered IRR (%)

		NEH (Hours)				
		-10%	-5%	3,500	+5%	+10%
Capex (€ MM)	+10%	9.3%	12.2%	15.1%	18.1%	21.1%
	+5%	11.8%	14.9%	18.0%	21.1%	24.4%
	2.8	14.5%	17.8%	21.1%	24.6%	28.1%
	-5%	17.6%	21.1%	24.7%	28.5%	32.3%
	-10%	21.1%	24.9%	28.9%	33.0%	37.2%

Levered IRR (%)

		Cost of Debt (%)				
		6.50%	6.75%	7.10%	7.25%	7.50%
Leverage (%)	80%	37.0%	34.9%	32.0%	30.9%	28.9%
	75%	28.0%	26.7%	24.9%	24.2%	23.0%
	70%	23.2%	22.3%	21.1%	20.6%	19.8%
	65%	20.3%	19.6%	18.8%	18.4%	17.8%
	60%	18.3%	17.8%	17.1%	16.8%	16.3%

Table 5. Sensitivity Tables.

Assuming that the project is 100% equity financed and a deviation of +/-5% over the selected operating drivers would result in return from 9.4% to 12.8% for an investor.

However, assuming that the project is partially financed with debt investors would substantially increase their returns. Sensitivity analysis shows how the marginal increase of IRRs is significantly affected in bullish scenarios (this rule also applies to bearish scenarios)

5.6. CONCLUSIONS

- The NPV of the project is higher than zero.
- The unlevered IRR is **11%**, which is higher than the WACC (7.6%).
- The levered IRR is of **21.1%**, which is greater than the cost of equity (14%).
- The payback period is **8.5 years**.

Therefore, we can say that the project is financially viable.

APPENDIX 1. Profit and Loss Acccount

Profit & Loss Statement

€ MM	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Installed Capacity (MW)	90.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	60.0
Hours per year (h)	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500
Production (GWh)	315.0	525.0	525.0	525.0	525.0	525.0	525.0	525.0	525.0	525.0	525.0	525.0	525.0	525.0	525.0	525.0	525.0	525.0	525.0	525.0	210.0
Price (€/MWh)	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Revenues	**47.3**	**78.8**	**78.8**	**78.8**	**78.8**	**78.8**	**78.8**	**78.8**	**78.8**	**78.8**	**78.8**	**78.8**	**52.5**	**52.5**	**52.5**	**52.5**	**52.5**	**52.5**	**52.5**	**52.5**	**21.0**
Total Revenues	**47.3**	**78.8**	**78.8**	**78.8**	**78.8**	**78.8**	**78.8**	**78.8**	**78.8**	**78.8**	**78.8**	**78.8**	**52.5**	**52.5**	**52.5**	**52.5**	**52.5**	**52.5**	**52.5**	**52.5**	**21.0**
Operational Costs (€/MW)	20.1	20.3	20.5	20.8	21.1	21.4	21.7	22.1	22.4	22.7	23.1	23.4	23.8	24.2	24.5	25.0	25.4	25.9	26.4	26.9	27.4
Operational Costs	**(6.3)**	**(10.6)**	**(10.8)**	**(10.9)**	**(11.1)**	**(11.3)**	**(11.4)**	**(11.6)**	**(11.8)**	**(11.9)**	**(12.1)**	**(12.3)**	**(12.5)**	**(12.7)**	**(12.9)**	**(13.1)**	**(13.4)**	**(13.6)**	**(13.9)**	**(14.1)**	**(5.7)**
EBITDA (€ MM)	**40.9**	**68.1**	**68.0**	**67.8**	**67.7**	**67.5**	**67.3**	**67.2**	**67.0**	**66.8**	**66.6**	**66.4**	**40.0**	**39.8**	**39.6**	**39.4**	**39.1**	**38.9**	**38.6**	**38.4**	**15.3**
Depreciation	(12.6)	(21.0)	(21.0)	(21.0)	(21.0)	(21.0)	(21.0)	(21.0)	(21.0)	(21.0)	(21.0)	(21.0)	(21.0)	(21.0)	(21.0)	(21.0)	(21.0)	(21.0)	(21.0)	(21.0)	(8.4)
EBIT (€ MM)	**28.3**	**47.1**	**47.0**	**46.8**	**46.7**	**46.5**	**46.3**	**46.2**	**46.0**	**45.8**	**45.6**	**45.4**	**19.0**	**18.8**	**18.6**	**18.4**	**18.1**	**17.9**	**17.6**	**17.4**	**6.9**
Interest Expenses (€ MM)	(6.26)	(16.70)	(20.87)	(20.18)	(18.79)	(17.40)	(16.00)	(14.61)	(13.22)	(11.83)	(10.44)	(9.05)	(7.65)	(6.26)	(4.87)	(3.48)	(2.09)	(0.70)	-	-	-
PBT (€ MM)	**22.1**	**30.4**	**26.1**	**26.6**	**27.9**	**29.1**	**30.3**	**31.6**	**32.8**	**34.0**	**35.2**	**36.4**	**11.4**	**12.5**	**13.7**	**14.9**	**16.1**	**17.2**	**17.6**	**17.4**	**6.9**
Tax (€ MM)	(7.0)	(9.6)	(8.2)	(8.4)	(8.8)	(9.2)	(9.6)	(9.9)	(10.3)	(10.7)	(11.1)	(11.5)	(3.6)	(4.0)	(4.3)	(4.7)	(5.1)	(5.4)	(5.6)	(5.5)	(2.2)
Net Income (€ MM)	**15.1**	**20.8**	**17.9**	**18.2**	**19.1**	**19.9**	**20.8**	**21.6**	**22.5**	**23.3**	**24.1**	**24.9**	**7.8**	**8.6**	**9.4**	**10.2**	**11.0**	**11.8**	**12.1**	**11.9**	**4.7**

APPENDIX 2. FCF

Free Cash Flow

€ MM	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
EBIT (€ MM)	28.3	47.1	47.0	46.8	46.7	46.5	46.3	46.2	46.0	45.8	45.6	45.4	19.0	18.8	18.6	18.4	18.1	17.9	17.6	17.4	6.9
Tax Over EBIT (€ MM)	(8.9)	(14.8)	(14.8)	(14.7)	(14.7)	(14.6)	(14.6)	(14.5)	(14.5)	(14.4)	(14.4)	(14.3)	(6.0)	(5.9)	(5.9)	(5.8)	(5.7)	(5.6)	(5.6)	(5.5)	(2.2)
Depreciation (€ MM)	12.6	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	8.4
Capex (€ MM)	(252.0)	(168.0)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Acc. Receivable	7.9	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	3.5
Acc. Payable	0.5	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.2	1.2	0.5
Changes in Working Capital (€ MM)	(7.3)	(4.9)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6
TV Capitalization Factor	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.4	1.4
Inflation[35]	1.0%	1.4%	1.4%	1.5%	1.5%	1.4%	1.4%	1.5%	1.5%	1.5%	1.5%	1.5%	1.6%	1.5%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%
Decommissioning	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	(21.0)
Unlevered Free Cash Flow (€ MM)	**(227.3)**	**(119.6)**	**53.2**	**53.1**	**53.0**	**52.9**	**52.8**	**52.6**	**52.5**	**52.4**	**52.3**	**52.1**	**38.4**	**33.9**	**33.8**	**33.6**	**33.4**	**33.3**	**33.1**	**32.9**	**(3.4)**
Discount factor	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
Present Value of CF (€ MM)	**(203.3)**	**(99.4)**	**41.1**	**38.1**	**35.3**	**32.8**	**30.4**	**28.2**	**26.1**	**24.2**	**22.5**	**20.8**	**14.3**	**11.7**	**10.8**	**10.0**	**9.3**	**8.6**	**7.9**	**7.3**	**(0.7)**
Interest Expense (€ MM)	(6.3)	(16.7)	(20.9)	(20.2)	(18.8)	(17.4)	(16.0)	(14.6)	(13.2)	(11.8)	(10.4)	(9.0)	(7.7)	(6.3)	(4.9)	(3.5)	(2.1)	(0.7)	-	-	-
Debt Amortization (€ MM)	-	-	-	(19.6)	(19.6)	(19.6)	(19.6)	(19.6)	(19.6)	(19.6)	(19.6)	(19.6)	(19.6)	(19.6)	(19.6)	(19.6)	(19.6)	(19.6)	-	-	-
Debt Raised (€ MM)	176.4	117.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Levered Free Cash Flow (€ MM)	**(57.2)**	**(18.7)**	**32.3**	**13.3**	**14.6**	**15.9**	**17.1**	**18.4**	**19.7**	**21.0**	**22.2**	**23.5**	**11.2**	**8.0**	**9.3**	**10.5**	**11.8**	**13.0**	**33.1**	**32.9**	**(3.4)**

Debt Evolution

Initial Debt (€ MM)	-	176.4	294.0	294.0	274.4	254.8	235.2	215.6	196.0	176.4	156.8	137.2	117.6	98.0	78.4	58.8	39.2	19.6	-	-	-
Increase in Debt (€ MM)	176.4	117.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mandatory Debt Repayments (€ MM)	-	-	-	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	-	-	-
Closing Debt (€ MM)	176.4	294.0	294.0	274.4	254.8	235.2	215.6	196.0	176.4	156.8	137.2	117.6	98.0	78.4	58.8	39.2	19.6	-	-	-	-

[35] Source: Global Insight Report

6. CONCLUSIONS

According to the results obtained after the analysis of the different drivers which define the viability of the proposed project, the following conclusions arise:

- From the point of view of the European and German Energy Strategies, the project fits the expectations and goals set by the authorities to reduce the energy dependence from third countries and/or regions as well as to increase the share of green energies within the energy source mix.

- It complies with all European and German Regulations applying in every legal or technical area.

- Regarding the technical aspects, although there are not many wind farms of similar size operating currently, all the methodology and equipment used had been tested previously with positive results. Besides, the specific conditions of the project in terms of allocation and technology can be extrapolated to be used with the equipment currently available.

- The Net Present Value is higher than zero, both unlevered (11%) and levered (21%) IRRs are higher than the minimum acceptable, and the payback period (8.5 years) is also within the expected time limit. Therefore, the project is financially viable

- The Environmental Impact Study developed shows that the project will not result in either large scale or widespread environmental damage.

Therefore, we can say that the project is in all aspects viable.