Deep water offshore wind technologies

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Abstract

This thesis is focused on offshore wind energy and aims to show the importance of using renewable energy sources for the production of ‘clean’ energy.

Onshore wind energy is in common use nowadays for the production of electricity but there are a number of drawbacks when using wind turbines on land. First of all the wind potential is not as high as the potential at sea conditions and is opposed by humans mainly due to the visual intrusion of a wind turbine and the noise of the rotating blades.

For the above reasons, wind turbines have started to be deployed offshore. The impacts that they have on the local environment are minimal, nobody can complain about the noise created or for the visual impact of a wind turbine located in deep sea water, and wind turbines can provide us with huge amounts of electricity because there are no obstacles to change the air flow path and wind velocity.

The scope of this project is to design a 495 MW deep water offshore wind park in order to take advantage of the current offshore technology used for clean electricity generation. A complete study concerning the location of installation of the offshore wind park, the wind potential of the proposed site, possible environmental impacts and an economical analysis of the components used for the operation of the offshore wind park, such as wind turbines, deep water foundation, maintenance and many more, are able to provide us with information about the future use of such technologies worldwide.

In our case, the study of the 495 MW wind park located in the Aegean Sea deep water showed us that deep water technology is still immature when compared with onshore wind technology. Although the wind potential is much greater offshore, thus producing more power than onshore wind turbines, the cost of larger wind turbines together with the foundations used for deep water wind parks is very high. It is imperative to use large size wind turbines in order to counterbalance the high initial capital investment.

At the current stage, the cost of constructing such an offshore wind park is as much as 0,089 Euro/kWh, while for the largest offshore wind farm (Horns Rev), the cost of construction was equal to 0.049 Euro/kWh.

This figure follows a decreasing trend due to the large wind potential, the multi-megawatt wind turbine technology commercialization and the knowledge gained from experience of such projects.

1. Introduction

During the last decade, awareness has increased about the change in climatic conditions worldwide, which in collaboration with the chronically inevitable exhaustion of petroleum(oil) resources and the exhaustion of the remaining ore energy resources such as coal and lignite, has increased interest in so-called renewable energy resources. Both in research and at an industrial production stage, efforts are being made to gradually adopt renewable energy resources that are going to be exempt from any environmental consequences.

The offshore environment offers a variety of renewable energy resources that are able to cover worldwide energy demands. The sea environment of our planet has huge amounts of energy in the form of heat, wave, tidal and sea winds. In the past there were a number of problems that arose, due to a lack of technological support, and the fact that the development of offshore forms of energy was unsupported, leading offshore energy to cover only a slight portion of worldwide energy production.

During the past decade however, there has been an increased interest in such forms of energy and recent studies have shown that the percentage of renewable energy production will increase gradually.

Independently from the remaining Renewable Energy Sources (R.E.S) of the offshore environment, energy production due to offshore winds seems to be the most dynamic and drastic solution to the energy production problem. A number of offshore wind farms are already in use, most of them installed in European countries. In particular, the countries of northern Europe, due to geographical, morphological, political and social reasons and issues, show more interest in such forms of energy. Although there is a specific report in one of the following chapters, it is worth mentioning at this stage that recently in Denmark the construction of the greatest worldwide offshore wind park was completed, with a total cost of approximately 270 million Euros[1] and with electrical production equal to 160MW[1].

Interest in offshore wind energy is continuously increasing and the future intentions of many countries include the construction of offshore wind parks in the following decades. At this stage, particular attention should be paid to the methods that are going to be used, in order to construct offshore wind parks so as not to alter the sea environment or harm sea animals that already have to cope with over fishing, pollution and a change in climatic conditions.

For countries that to a large extent are covered by sea and if the sea conditions that exist favor the construction of offshore wind farms, offshore wind turbines can lead to an environmentally friendly and productive way to cover their electrical energy demands.

The cost of the electrical energy produced will gradually decrease with the construction of even bigger offshore wind parks while the cost of operation and maintenance will be low due to the natural way that they operate.

The current view allows us to suppose that in the future, the production of electrical energy with the use of offshore wind is going to have huge development due to the high population demand for clean and cheap energy.

2. Historical Review

The use of wind energy by humans was introduced many centuries ago.
Figure 1 shows the oldest human construction that still exists and was used for the production of energy from wind.

Figure 1: The oldest construction used for the production of energy from wind

This construction can be found in Persia and dates from the 6th century B.C.
Wind energy was used for many different activities such as for the irrigation of crops, milling grain, pumping water and pressing oil from seeds. The blades of the wind mills were made of reeds or wood and were attached to a central vertical pole, thereby rotating around a vertical axis.
The first time that wind energy was used for the production of electrical energy was in 1885 in Denmark at the high school of Askov[2].

Figure 2: The first wind turbine at Askov

Pour la Cour converted an old wooden wind mill into the first wind turbine ever, which covered the energy demands of Askov high school.

From 1885, the use of wind energy for the production of electricity progressed but all the wind farms were located onshore.

The first thoughts of locating wind turbines offshore came immediately after 1930 when it was suggested that wind turbines be placed on pylons. Although these suggestions were never used, they made a promising start and in 1972, approximately 40 years after the original idea, Dr. William E Heronemus, professor at M.I.T University introduced the idea of large floating wind turbine platforms in order to produce electrical energy.

In 1990, 18 years after the time that professor William E Heronemus first had his vision for the construction of floating wind turbines, a company called ‘World Wind’ constructed and installed the first offshore wind turbine at sea.

This offshore wind turbine was located in Nogersund, 250 m offshore, in 7 meter water depth off the North part of Sweden and had a rated power of 220 KW[3].This offshore wind turbine can be seen in figure 3.

Figure 3: The first offshore wind turbine at Nogersund-Sweden

A year later, in 1991, at Vindeby in Denmark and at a distance of 1.5 to 3 Km offshore, the first large commercial offshore wind farm was constructed, having a rated power of 5MW and consisted of 11 Bonus wind turbines of 450KW each. The water depths at that site are from 3 to 6 meters and the annual energy production is equal to 12 GWh/year. This site is shown in figure 4.

Although we are going to talk about the current development of offshore wind farms at a later stage, it is worth mentioning that in 1995, Denmark constructed its second offshore wind park at Tunoe Knob as shown in figure 5. This offshore wind park has a power output of 5MW and consists 10 Vestas wind turbines of 500KW placed at water depths between 2 and 6 meters and the annual energy production is equal to 16GWh/year[4].

Figure 4: The first large commercial offshore wind farm at Vindeby-Denmark

Figure 5: Installation of a 500KW Vestas wind turbine at Tunoe Knob-Denmark

Holland is the country that developed offshore wind farms immediately after Denmark. At this stage we should make the separation between sea environment and offshore environment clear because in Holland the first two wind parks were installed not in sea water but in the waters of Lake Ilsselmeer. In 1994 at a site called Lely in the region mentioned above, the first sea environment wind park for Holland was constructed at water depths between 5 to 10 meters depth with a rated power of 2 MW, and consisting of four 500KW Nedwind wind turbines. This wind park is shown in figure 6. Two years following the end of the construction of Lely's wind park in a region called Irene Orrin in the same lake, the second wind park of 16.8 MW was constructed. 28 Nordtank 600KW wind turbines were used for this site[5].

Figure 6: The four 500kW Nedwind wind turbines of Lely's wind park

As was previously mentioned, the first step towards harnessing offshore wind energy was taken in Sweden. Eight years after the first installation in Swedish waters and in 1998 at Bockstigen site, north of Gotland island, 5 Wind World wind turbines were installed with a rated power of 500 KW each. These wind turbines were installed at a distance of 3Km offshore at a water depth of 6 m.

Great Britain joined the leading group of countries that test offshore wind energy and by the year 2000 the first wind park has been constructed in an area called Blyth in south-west England with a rated power of 4 MW. This park includes two Vestas wind turbines of 2 MW each that are placed at a distance of 800m offshore at a water depth of between 6 and 11 m.

Figure 7: The two Vestas wind turbines of Blyth's wind park

The next offshore wind park that was constructed can be seen in Denmark in the port of Copenhagen and can be seen in figure 8.

Basically, this was the first large offshore wind park with a rated power of 40 MW. It includes 20 Bonus Wind turbines of 2 MW each that are placed at a distance of 3 Km offshore and at a water depth of between 3 to 6 m. Middelgruden, as it is called, had a total cost of 54 million Euros and construction ended in 2000[6].

Figure 8: Middelgrunden wind park which is 3 km offshore from Copenhagen

By 2000 and 2001, two new offshore wind parks were constructed in Sweden.

The first one is Utgrunden and is situated between Oland island and the shore. It uses 7 Enron wind turbines at a rated power of 1.425 MW each, which are placed 8 Km offshore at water depths from 7 to 10 meters.

The second one is Yttre Stengrund, north of the island of Oland and includes 5 NEG-Micon Wind turbines of 1.425 MW each at a distance of 5 Km offshore and at water depths from 6 to 10 m deep[7].

Moving on, in 2002 there was the construction of the next offshore wind park for Denmark, close to Samso island with a total electrical production power of 23 MW. It includes 10 Bonus wind turbines of 2.3 MW which are placed at water depths of 20 m offshore, 3.5 Km offshore.

In 2003, interest in offshore wind energy was intense. Four new offshore wind parks were constructed in three different countries and have been operational since then.

The first offshore wind park for Ireland was then constructed, and at a first stage, it includes 7 Airticity wind turbines of 3.6 MW each, which are located at a distance of 10 Km offshore at water depths between 5 to 25 m. It is worth mentioning that by the end of 2007 the complete construction of Arklow Bank will have finished and it will be the world’s largest offshore wind park including 200 wind turbines with a total power of 520 MW.

Great Britain constructed North Hoyle, its second offshore wind park, 6 Km offshore from North Wales. It includes 30 Vestas wind turbines of 2 MW at water depths of 10 to 20 m.

The next two offshore wind parks were constructed in Denmark. The first one is Frederikshavn with a rated power of 10.6 MW and includes 4 Bonus wind turbines of 2.65 MW each. The second one is Horns Rev offshore wind park which is the largest offshore wind park up till now with a total power production of 160 MW. In one of the next chapters there is going to be an analytical presentation of this site. At this point it is appropriate to mention that it includes 80 Vestas wind turbines of 2 MW each that are located at a distance between 14 to 20 Km offshore and at water depths between 6 to 12 m[9].

Figure 9: Horns Rev, the largest commercial wind park of the world

At this stage, the historical review has reached its end having presented all the offshore wind parks that were constructed during the past years. There are a number of studies for the construction of even more offshore wind parks that are going to be mentioned at a later stage. In table 1, all the offshore wind parks that were mentioned before are presented and in figure 10 there is a graphical output showing the total wind power output at a worldwide stage. Although there is no information for the year 2003, it is easy to calculate and see that the percentage of offshore wind power installed to the total wind power installed is equal to 0.37% as can be seen in table 2. This percentage will keep increasing due to the data and knowledge obtained from the early designed offshore wind farms and will lead to an increase in offshore installations each year.

Name	No of wind turbines	Brand-Rated power	Rated power of offshore wind park (MW)	Year	Country	Type
Nogersund	1	Wind World-220 kW	0.22	1990	Sweden	Tripod on solid rock
Vindeby	11	Bonus-450 kW	4.95	1991	Denmark	Gravity based
Lely	4	NedWind-500 kW	2	1994	Holland	Monopile
Tunoe Knob	10	Vestas-500 kW	5	1995	Denmark	Gravity based
Irene Vorrink	28	Nordtank-600 kW	16.8	1997	Holland	Inland-Sea
Bockstigen	5	Wind World-500 kW	2.5	1998	Sweden	Monopile
Blyth	2	Vestas-2 MW	4	2000	England	
Middengrunden	20	Bonus-2 MW	40	2000	Denmark	Gravity based
Utgrunden	7	Enron-1.425 MW	10	2000	Sweden	Monopile
Yttre Stengrund	5	NEG-Micon-2 MW	10	2001	Sweden	
Samso	10	Bonus-	23	2002	Denmark	

		2.3 MW				
Arklow Bank	7 (200) *	GE Wind- 3.6 MW	25.2(520)**	2003	Ireland	
North Hoyle	30	Vestas- 2 MW	60	2003	England	
Horns Rev	80	Vestas- 2 MW	160	2003	Denmark	Monopile
Frederikshavn	4	Vestas- 2.65 MW	10.6	2003	Denmark	
Total	**224**		**374.27**			

*Number of total wind turbines installed at Arklow Bank wind park by the year 2007

**Rated power in MW of Arklow Bank wind park by the year 2007

Table 1: Offshore wind parks installed

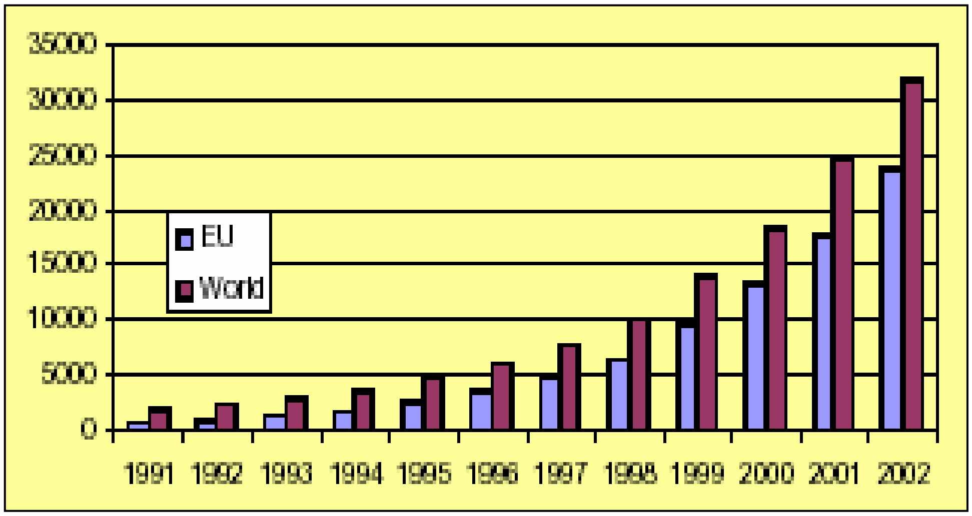


Figure 10: Graphical output showing the total wind power output (MW) at a worldwide stage[9].

Year	**Power of wind turbines installed (MW)**	**Power of wind turbines installed offshore (MW)**	**Percentage (%)**
2002	32037	118,47	0,37

Table 2: Percentage of wind turbines placed offshore

2.1 Advantages of offshore wind parks

In many countries, especially European, geographical conditions and the centralization of population does not allow the construction of wind farms onshore. This is evidenced in countries such as Denmark and Holland which are practically flat with low ground elevation and are densely populated. These conditions are not met offshore because there, there are large continuous areas with no obstacles for the creation of high wind speeds. The higher wind velocity at a sea environment is another main reason for the construction of offshore wind parks. For areas that are located 10 Km or more from land it is usual to meet an increase in wind velocity of about 20%. Given the fact that wind energy increases according to the cube of the velocity factor it is obvious that wind energy can be as much as 70% higher than wind speed onshore. It is calculated that economically optimized wind turbines placed offshore can produce around 50% more energy than those placed onshore. We should note that in countries such as Great Britain and especially in the region of Scotland, installing wind turbines either onshore or offshore means no great difference because wind turbines are located at sites where wind velocity is much greater than the usual velocities achieved at other onshore areas.

Another very important reason that leads to the construction of offshore wind parks is the huge amounts of energy that can be produced due to offshore sea winds. For low and stable intensity winds, the water surface is fairly rigid, but when wind speed increases, there is a large percentage of wind energy that is consumed for the creation of waves increasing the roughness of the water surface. Water roughness progressively decreases when the wave cycle is complete. We can see that the water surface alters its roughness according to the wind velocity but on comparing offshore with onshore roughness we observe that offshore roughness is lower than onshore. Low roughness means that the increase of wind speed according to the distance from the water surface is not as intense as for onshore, leading to the use of shorter wind turbines than for onshore. Usually the height of the tower of the wind turbine is equal to the diameter of the rotor or even greater. For situations offshore we can use towers whose height is equal to 75% of the diameter of the rotor leading to an important decrease in the construction cost.

Finally, it should be noted that offshore wind speed flow is less turbulent than onshore, leading offshore wind parks to have a longer life than the ones onshore. The temperature changes in the atmosphere above the sea are much smaller than the ones onshore. Sun radiation runs through the sea surface many meters below the sea surface in contrast with onshore, where sun radiations heat up the upper part of the land surface which becomes much warmer. This results in a temperature difference between the air and the surface which is much greater on land than offshore, making the wind flow more turbulent.

A less turbulent flow means that the fatigue load will be much smaller and the life cycle of the wind turbine will be much greater. Although there are no exact calculations at this stage, it is said that a wind turbine which is designed for a life cycle of 20 years for onshore installation can be used for an offshore installation with a life cycle of 25 to 30 years.

2.2 Disadvantages of offshore wind parks

The main reason for the late development of the utilization of offshore wind energy is the high construction cost. During the past four years the acquisition cost of a wind turbine has decreased around 20% per KW. The onshore installation cost due to the increase of the size of the wind turbines has also decreased but the cost of installing a wind turbine offshore remains virtually stable. The two main parameters that are responsible for the high cost is the marine foundation cost and the cost of electrical connection with the shore. In order to make this fact more clear it should be mentioned that for the onshore wind park Rejsby Hede in Denmark, which contains 39 wind turbines of 600 KW each, the total cost for each wind turbine was 660000 Euros. The cost of the foundations was about 6% (39600 Euros) and the cost of the electrical connection was equal to 3% (19800

Euros). At the offshore wind park of Tunoe Knob in Denmark again, there are 10 wind turbines of 500 KW each, placed at a water depth of 5 to 10 meters. The total cost for each wind turbine was equal to 1.035 million Euros where the cost of the marine foundations was equal to around 23% (0.238 million Euros) of the total cost and the cost of the electrical connection was equal to 14% (0.145 million Euros) of the total cost[13]. In figure 11 there is a graphical presentation of the above. Another example is the offshore wind park of Bockstigen in Sweden where the total cost was around 4.7 million Euros and the cost of installation per KWh was equal to 0.57 Euros/KWh, which is around 15 to 20% higher than the onshore corresponding one of equal power production.[13]

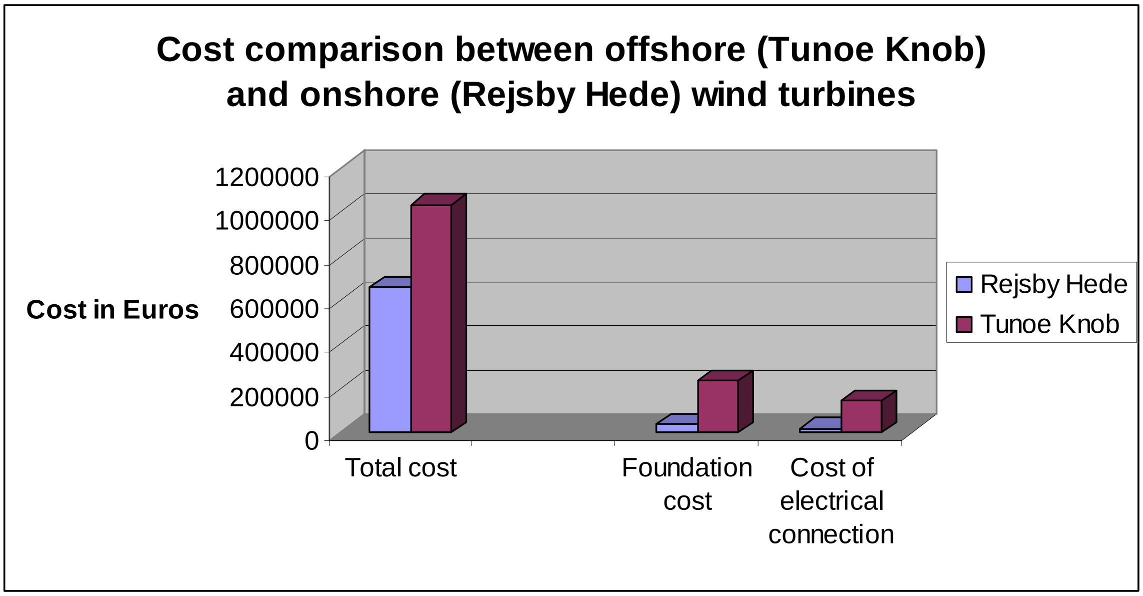


Figure 11: Cost comparison between offshore (Tunoe Knob) and onshore (Rejsby Hede) wind turbines[3]

The major disadvantage of offshore wind parks is limited access for operation and maintenance. In figure 12, the graphical presentation of the relation between availability and accessibility for offshore wind parks can be seen. Availability is the function of ease of access, of the quality of maintenance and operation, and of the reliability of the wind turbines.

In red in figure 12, the region which is based for the design of onshore wind turbines can be seen. As long as reliability increases, there is an increase in the availability for offshore wind parks which are represented by the green and yellow regions in figure 12.

From figure 12, the difference in all three regions between onshore and offshore wind turbines can be seen.

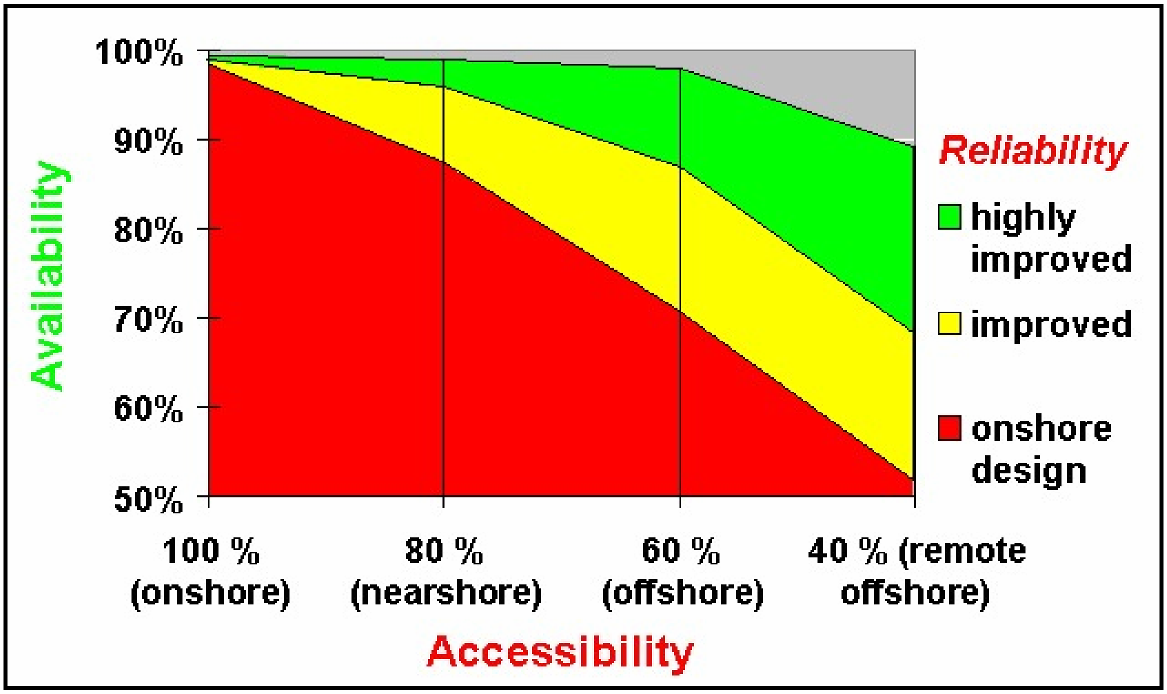


Figure 12: Relation between availability and accessibility for offshore wind parks[7]

3. Design of offshore wind parks

3.1 Design of wind turbines

The design of multi-megawatt wind turbines is certainly a positive factor for the development of offshore wind parks. The move towards larger wind turbines can be seen in figure 13 where the progress made in the power produced and the size of prototype wind turbines is presented.

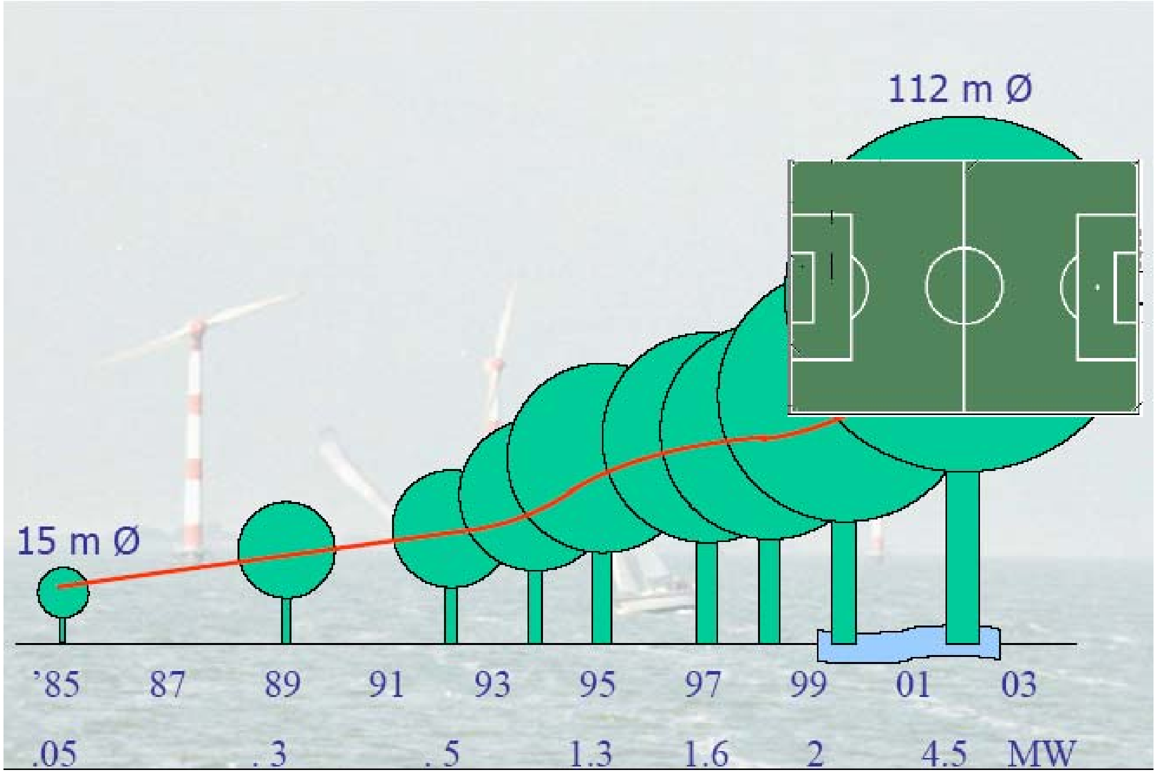


Figure 13: Development in power produced and size of prototype wind turbines[10]

It is impressive that the latest prototype wind turbine, which was designed by Enercon company in order to be installed at Magdenburg in Germany, has a power output of 4.5 MW and a diameter equal to 112m, or equal to the length of a football pitch.

Because of the increased cost of foundations and the electrical connection cost, it is imperative to use large size wind turbines in order to counterbalance the high initial capital investment. A close look towards the future shows that forthcoming offshore wind parks will use wind turbines able to produce much greater power than the already installed wind turbines. In table 3 the largest commercially available wind turbines are presented. The power produced varies between 1.8 MW to 2.5 MW and the rotor diameter varies from 66 to 80 meters.

	Vestas 66	**Bonus 2**	**Nordex 80**	**Neg-Micon 2**	**Enron 2**	**Enercon 70**
Rated Power(kW)	2000	2000	2500	2000	2000	1800
Rotor Diameter(m)	66	76	80	72	70.5	70

Table 3: The largest commercially available wind turbines[10]

Moving on to prototype wind turbines, table 4 shows the largest prototypes which are not commercially available yet. It can be observed from table 4 that the rated power which can be achieved at this period is equal to 5 MW and has a rotor diameter equal to 115 m.

Manufacturer	GE wind	Enercon	Vestas	NEG-Micon	Nordex	REPower	Pfleiderer	DeWind
Rated power (MW)	3.6	4.5	3	2.75	5	5	5	3.5
Diameter (m)	100	112	90	90	115	115	115	90
Prototype date	April 2002	Mid 2002	May 2002	Late 2002	2003	2003	2004	2003

Table 4: Largest prototypes currently under development[14]

The unique features of the offshore environment affect the characteristics of the offshore wind turbines. The highly corrosive environment, together with the need for weight reduction, has led to the design of composite material blades. Due to the latest developments concerning the reduction of the price of carbon fibers, carbon fibers in collaboration with epoxy resins were adopted for the design of the blades. As for the design method, polymerization at air gap at high temperature and pressure will be the one that will dominate.

Because of the increase in the size of the wind turbine there is a possibility that the gearboxes that already exist and are used today will not be able to cope with the new multi megawatt wind turbines. The gearboxes used nowadays consist of 3 stages with the pinion mechanism using planets and the 2 upper stages being parallel with helical serrations. The need to adopt another scale will increase the complexity, so there is a possibility of developing a system without a gearbox.

A move towards the design of systems with varying speed can also be observed. This variation of speed has the advantage of making it possible to avoid the creation of noise which might create dangerous frequencies for the design that can lead to the destruction of the wind turbine mechanisms. This is very important for offshore wind turbines because it is not possible to calculate these frequencies precisely and they might change during the wind turbines life cycle. This type of gearbox is called asynchronous gearbox and is the most promising gearbox system.

3.2 Wind turbine pylon design

The pylon of a wind turbine can be of three different types as presented in figure 14.

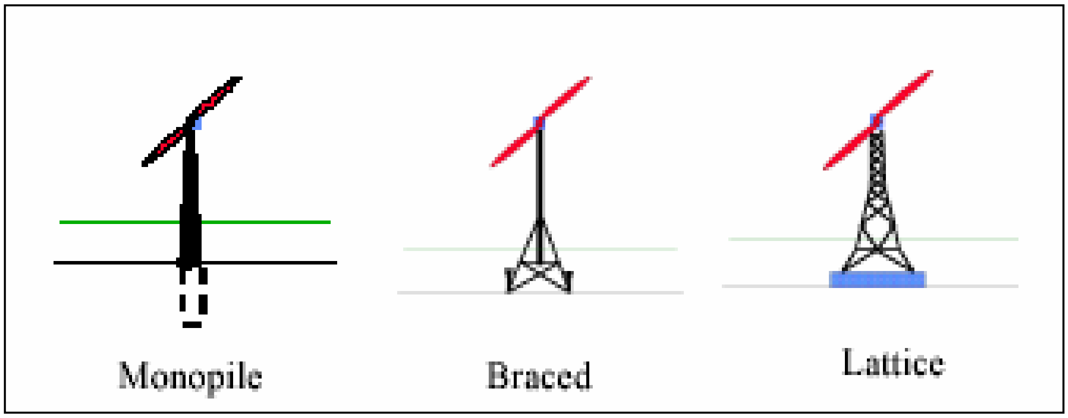


Figure 14: Three different types of pylon design.

The first type (Monopile) consists of a pylon which is installed at a specific depth inside the sea subsoil or it is placed on it according to the type of the foundation. The second type (Braced) is basically a vertical beam on which the turbine rotor is placed and it is supported by more vertical beams at its base. The third type (Lattice) is basically a net that is placed on a base at the sea bed.

Concerning the design of the pylon it should be noted that loadings due to tidal currents and waves as well as the chance of ice collision, are points that cannot be met at onshore wind turbines. Calculation of wave loading requires knowledge of the wave characteristics of the area of construction and the use of special stochastic models, which need great effort.

Apart from wave loading, wind loading should be also calculated. As it was previously mentioned the velocity of offshore winds can be as high as 20% more than the velocities that are met onshore. But because the water roughness increases with the wave height under extreme weather conditions, the difference in the wind velocity is smaller. In figure 15 you can see the velocity difference per height for offshore (z=0.01 m) and onshore (z=0.03 m) conditions.

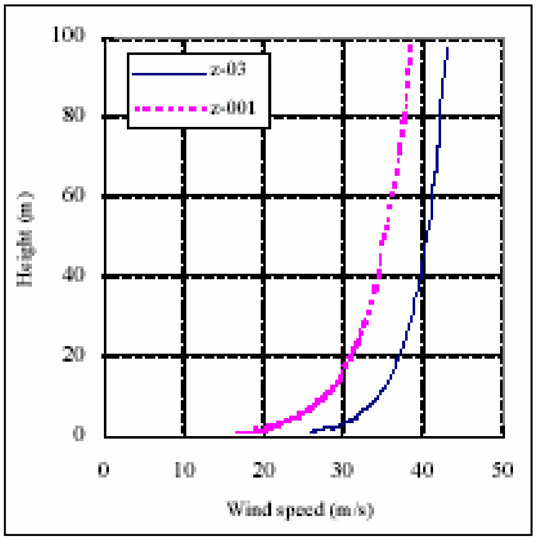


Figure 15: Speed distribution at extreme conditions for onshore (surface roughness z = 0.03 m) and offshore (surface roughness z= 0.01 m) designs per height.[15]

This difference might not be important but the air pressure is proportional to the square of the velocity so there is an important difference between the statical and dynamical loading. This can be seen in figure 16 where the percentage increase of pressure loading due to wind as a function of the height difference from the water surface is presented.

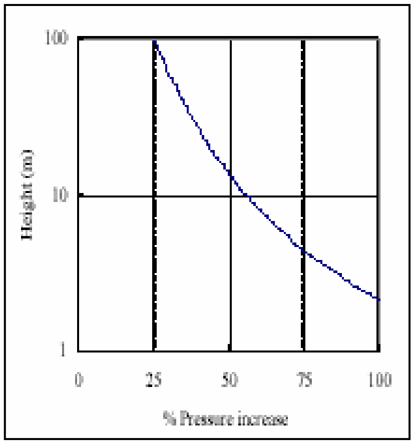


Figure 16: Percentage increase of loading pressure due to wind as a function of the height difference from the water surface.[15]

From the figure above it can be seen that the air pressure at sea environment can be 20 to 30% greater than the onshore one, a point that should be taken into consideration when designing the pylon.

At this stage it should be noted that the majority of pylons that have been designed up to now and will be designed in the future belong to the first two types that were presented earlier on.

3.3 Foundation design

The foundation of the pylons of wind turbines can be done using four different ways.

3.3.1 Gravity based

The first one is gravity based foundation and can be seen in figure 17.

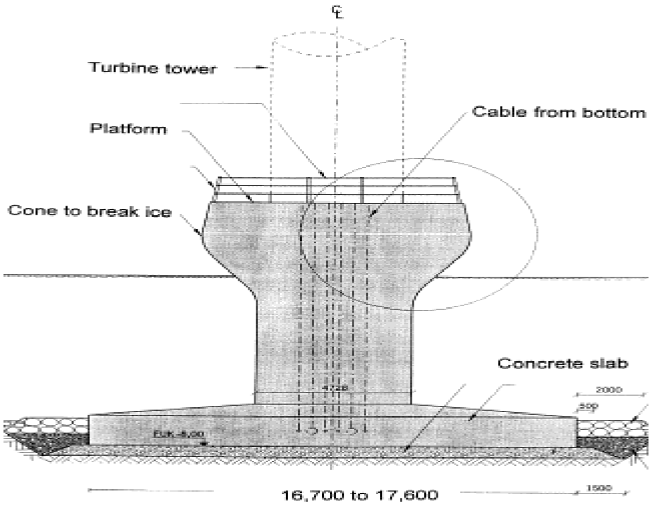


Figure 17: Gravity based foundation used for Middelgrunden wind park[16]

The majority of the wind turbines placed in Danish waters are of this type. These types of foundations are constructed in a dry dock from concrete slab and then floated to the point of installation. At this stage, the concrete slab base is filled with sand, concrete and gravel and is placed in the soil. Recently there was a suggestion for designing steel cylinders based on the construction of a circular structure base in soil and then subsequently filled with a high-density mineral (Olivine) in order to achieve the most appropriate weight in order to withstand the sum of the reacting forces on it. Using this method, the base is much lighter allowing their installation to be done with the same crane vessel used for installing the wind turbines. This helps the foundation and the wind turbine itself to be in an upright position while being exposed to overturning moments of wind and wave impacts on the turbine’s rotor and support structure. The weight of the foundations has to be increased when used in deeper waters in order to be able to withstand the reacting forces. The part of the structure penetrating the water is designed in a conical form as can be seen from figure 17 in order to reduce the ice impact when ice is present. This type of foundation requires sea bed preparation to be carried out. The sea bed must be levelled and prepared with a layer of crushed stones in order to accept the base of the wind turbine.

Nowadays, cost optimization of the offshore wind turbine foundations has led engineers to abandon the above method and adopt steel foundation instead of concrete ones. This design uses a steel structure consisting of a circular frame with integral stiffeners and a centrally mounted steel column to erect the wind turbine tower. Using steel foundations we have weight savings and installation mobility. These steel structures do not have to be designed onshore or in dry dock but can be constructed at distant ship yards close to the point of installation and then moved onsite for the actual installation. Again the sea bed has to be prepared in order to accept the steel structure.

Gravity based foundations are used for water depths up to 10m.

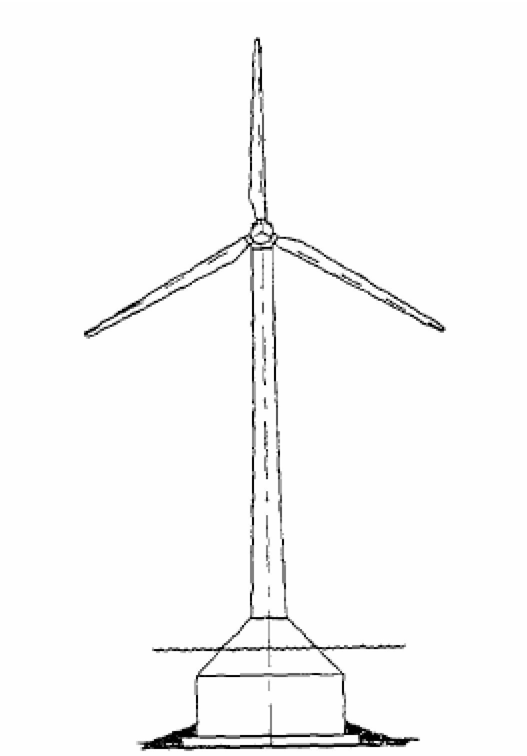


Figure 18: Complete gravity based support structure

3.3.2 Monopile

This type of foundation represents the most commonly used solution for installations at water depths of up to 25m. Due to the simplicity of the structure no special fabrication method is required. A pile is driven into the sea with the use of a piling or vibrating hammer and placed firmly in the sea bed. In situations where the sea bed is very stiff, drilling technique will be required. The way that the pylon is going to be placed in the sea bed depends on the soil characteristics, the water depth and the experience of the team that is going to do the installation. This method was used for the installation of the foundations of the largest offshore wind park of the world, Horns Rev offshore wind park in Denmark.

This type of foundation needs attention during the design stage. A point of interest is the assessment of the properties of the soil because uncertainties can lead to a design with different natural frequency than the desired one, resulting in problems due to the effect of the load forces.

The pile diameters are about 3 to 5 m and the pile penetration to the sea bed can be from 18 to 25m. The monopile structure does not require any sea bed preparation but it is sensitive to scour, so scour protection is needed, such as seaweed or shingles. Due to the above, installation of a monopile foundation using a jack-up platform at a demanding environment is estimated to take approximately 30 hours while removal of the monopile from the sea bed can be done easily with the use of a vibration hammer or by cutting the pile at a point close to the soil.

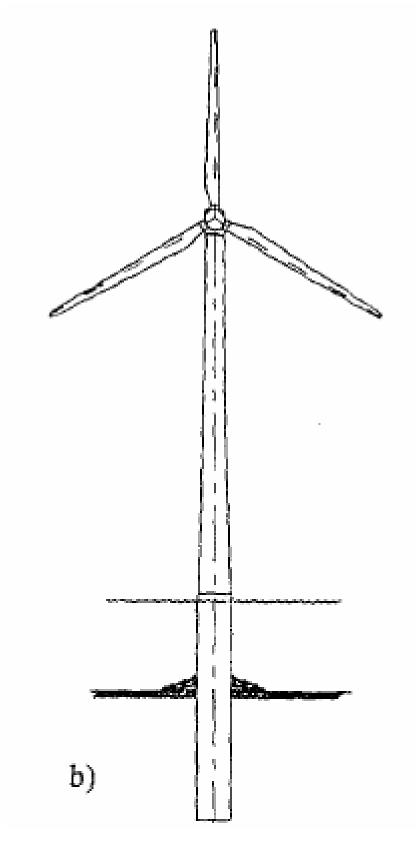


Figure 19: Monopile support structure

3.3.3 Tripod support structure

For water depths greater than 20m, a tripod is taken to be the most appropriate way of foundation. Only one wind turbine has a tripod base at this moment and is the first wind turbine that was installed at Nogersund in Sweden. Tripod bases have the advantage that they need little or no scour protection compared to the previously mentioned types of foundations.

It is made of a central column and three piles that are driven into the sea bed and connected to the frame through sleeves in the three corners. Apart from filling the central cylinder with grout in order to keep the cylinder in a rigid position, no sea bed preparation is needed. When placed in shallow waters such as below 7 m there is always the problem of service vessels collision to a part of the structure.

Although it has been used only once in the past, this support structure has the potential for sites far away from shore and thus for deeper water to be involved. Manufacturing at great distances from site are not considered to be a problem due to the tripod’s light weight design. Tripod foundation is most cost effective at larger water depths, particularly in areas without ice close to the wind park.

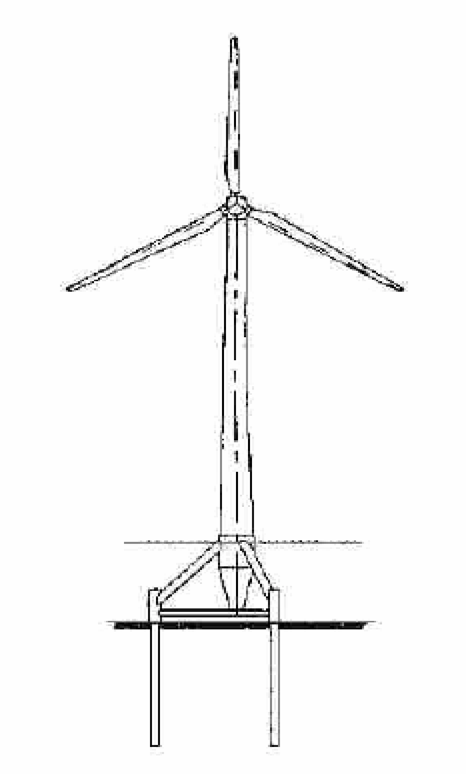


Figure 20: Tripod support structure

A variant design of the tripod base that has never been used is the tripod base under pressure as can be seen in figure 21. It was not possible to collect any more information about this type of tripod, but as you can see from the figure below, the three cylindrical bases are stabilized at the sea bed with the use of pressure difference. This creates an air gap under each cup which keeps them stabilized so that the central pylon, that is connected with the use of a net of beams with these cups, is stable under all conditions.

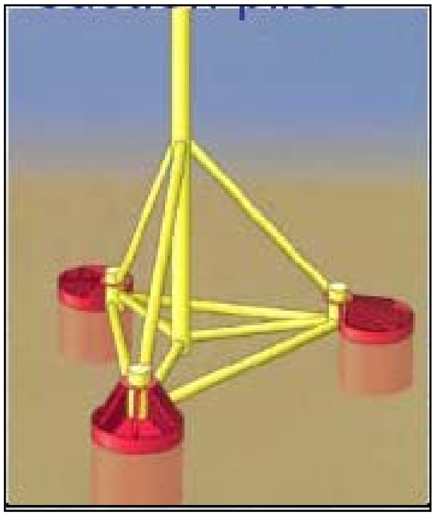


Figure 21: Tripod base under pressure

3.3.4 Floating support structure

This type of foundation is not based on placing the pylon of the wind turbine under the water since the wind turbine is a floating construction that is placed at a certain area above the sea surface. The idea of placing a wind turbine on a floating platform has a number of advantages such as reduced installation cost, less maintenance cost and less removal costs at the end of its life. The most important point is that these types of structures can be placed at water depths of 50 meters or more, a fact that is really important for countries that have a slight percentage of their sea precincts with shallow waters and their largest percentage with deep waters. The basic disadvantages of such systems are the dynamic interaction of the floating platform, the wind turbine itself, and the difficulty of designing the platform and the anchoring system. Until today, no floating platform has been produced.

Wind turbines can be placed either on single or multiple turbine floaters. Studies have shown that the cost for a multiple turbine floater would be very high and there were a number of inquiries about the ability of such a design to withstand extreme wave loading conditions. For this reason, such designs would have to share anchors cost and provide wave stability or even produce wave power from the platform itself apart from the power production of the wind turbines. In order to optimize power production from floating platforms, the platform will have either to yaw towards the wind direction when wind direction changes or to compromise the energy production when the wind shifts off the prevailing direction. Figure 22 shows a number of multiple turbine floater designs.

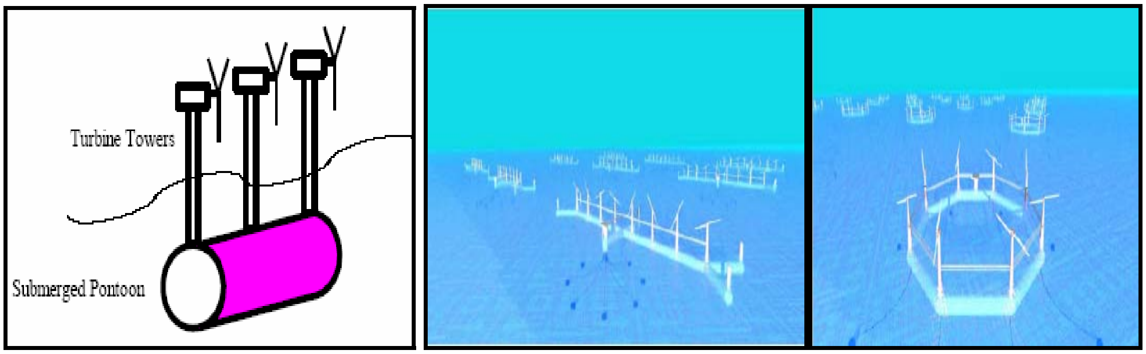


Figure 22: Multiple Unit Floating Offshore Wind farm (MUFOW concept)

In case each wind turbine is placed separately, the shape of the platform depends on the type of mooring system used, because the mooring method dictates much of the fundamental platform architecture.

The first one is with the help of anchoring lines where a part of it is placed on the sea bed. This type is called 'catenary systems’ and is shown in figure 23.

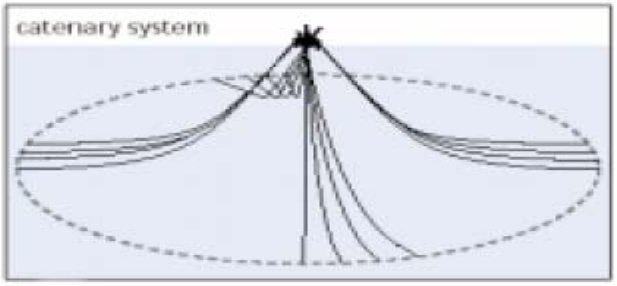


Figure 23: Anchoring lines where a part of them lies on the sea bed (Catenary system)

The main advantages of catenary systems are the relatively low cost of anchors and the potential to be deployed in shallow waters. Their main disadvantage is that the tension of the anchor line is generally insufficient to provide platform stability because the center of the reacting forces is above the center of buoyancy, making the floating platform overturn. Ballast must be added to provide stability, or depending on the size of the wind turbine, the weight of the wind turbine itself will reduce the height of the point of reacting forces, thus making the whole system more stable. Platform dynamics must be studied, complexity increases and the cost of such systems also increases.

The second type is the one that has completely stretched anchoring lines as shown in figure 24 and is called ‘Taut Leg’ system.

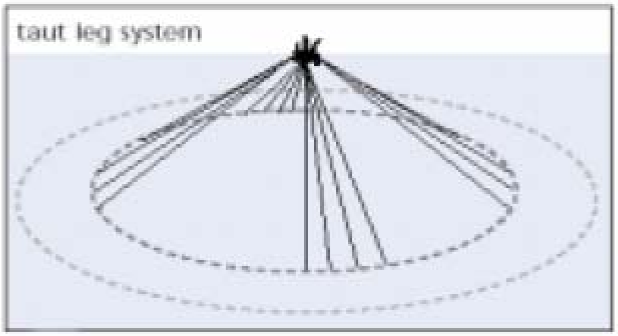


Figure 24: Taut Leg system

Taut leg systems have the advantage of smaller footprint and less mooring line needed as water depth increases when compared with catenary systems. Such systems have the advantage of being able to submerge the largest portion of the structure below the water surface thus minimizing the wave loads acting on it and increasing the stability of the whole system.

The third way is the ‘Tension-leg’ platform which is presented in figure 25.This way is the most stable and is possibly going to be the best choice with the lowest risk factor compared with the previous ways. The structure is submerged by vertical or taut angled tendons anchored to the sea bed. The platform is kept below the water surface thus minimizing the wave loads and maximizing the platform stability by moving only parallel to the sea bed.

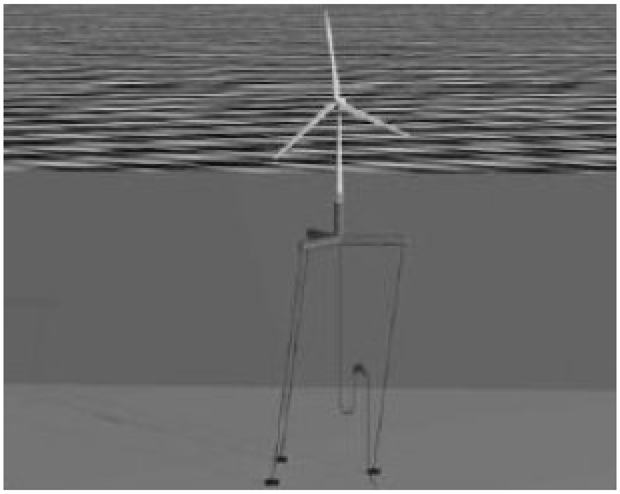


Figure 25: Tension-Leg platform

Another way that was suggested is the use of a vessel that has a number of wind turbines attached to it in order to be able to move according to the wind and weather conditions. A vessel like the one mentioned above can be seen in figure 26.

Figure 26: Floating Vessel

The next method is the one shown in figure 27, a single turbine placed on a buoyancy floater. When in a stable position, anchoring lines keep the design at a steady point. Using this way, the horizontal vibration of the vessel is minimized but because the center of gravity of the wind turbine will be relatively high, a large dimension vessel will be needed in order to give the proper lift and to reduce the center of gravity.

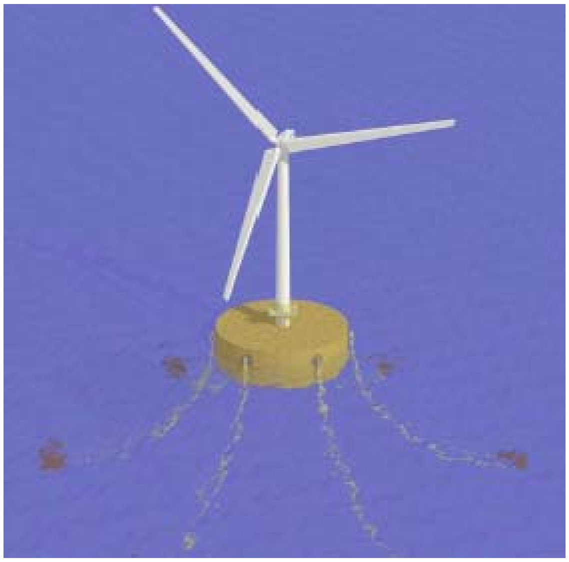


Figure 27: Single wind turbine placed on a buoy floater

Designs based on this method are the ones shown below and might be used in the future.

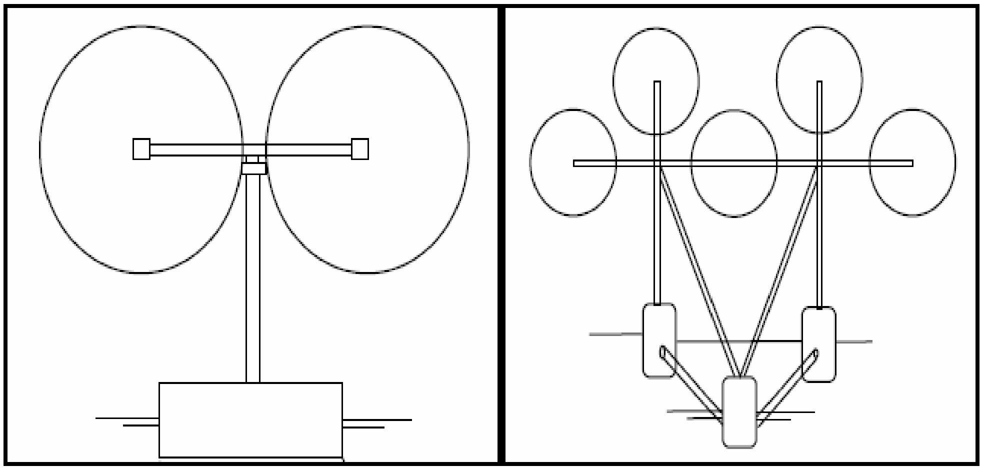


Figure 28: Single floater and triple floater having two or more wind turbines installed on them

Finally it is worth mentioning that the life cycle of the foundations is 50 years and for the wind turbines 25 years. If the foundations could be re-used, this would result in a large reduction in the cost of electricity production from offshore wind. It was calculated that for Denmark, this reduction would be of the size of 25 to 33 %.[10]

To sum up, all types of foundations, their applications, and the advantages and disadvantages of each type of foundation can be seen in table 6.

Foundation type	Applications	Advantages	Disadvantages
Monopile	Used at most conditions, especially for shallow waters, up to 6 m diameter	Simple and light design, no sea bed preparation needed, insensitive to scour	Expensive installation, difficult to remove, flexible at water depths, may require pre-drilling the seabed
Multiple piles (Tripod)	Most conditions, suits to water depths above 30 m.	Applicable to greater water depths, no or limited sea bed preparation, rigid and versatile	Not applicable to shallow waters, expensive construction and installation, makes boat access difficult, increases the ice load.
Concrete gravity base	All soil conditions	Float out installation	Expensive due to large weight
Steel gravity base	All soil conditions	Lighter than concrete, easy transportation and installation, reduces costs ,same crane used for foundation and turbine erection	Requires cathodic protection, costly when compared with concrete for shallow waters
Mono-suction caisson	Sand, soft clays	Inexpensive installation and easy removal	Limited range of materials used for installation
Multiple Suction caisson(tripod)	Sand, soft clays, deeper water than Mono-suction caisson	Inexpensive installation and easy removal	Limited range of materials used for installation, more expensive construction than Mono-suction caisson
Floating	Deep waters up to 100m	Inexpensive foundation construction, less sensitive to water depths, lower wave loads	High mooring and platform costs, excludes fishing, recreation and navigation from most areas of a farm

Table 6: Foundations types, applications, advantages and disadvantages of each type

3.4 Evaluation of offshore wind

Nowadays, the offshore wind power market is growing very fast. Especially after the addition of two of the largest offshore projects in the history of offshore wind power, Middelgrunden in the year 2000 and Horns Rev in the year 2002, installed wind capacity has increased tremendously when compared with the whole period between 1991 and 2000.

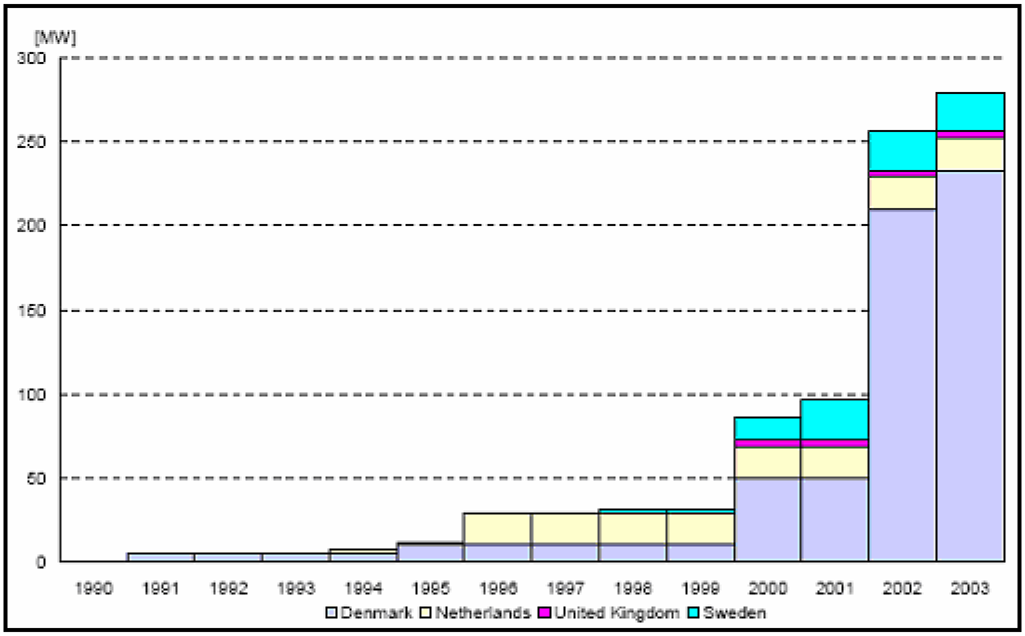


Figure 29: Realized offshore wind power[8]

Note that between 1991 and 2002 there is an increase in the annual average capacity of the order of 43%. This figure keeps increasing for the year 2003. For the years 2004 and so on, wind power may become the most powerful tool for energy production as can be seen in figure 30.

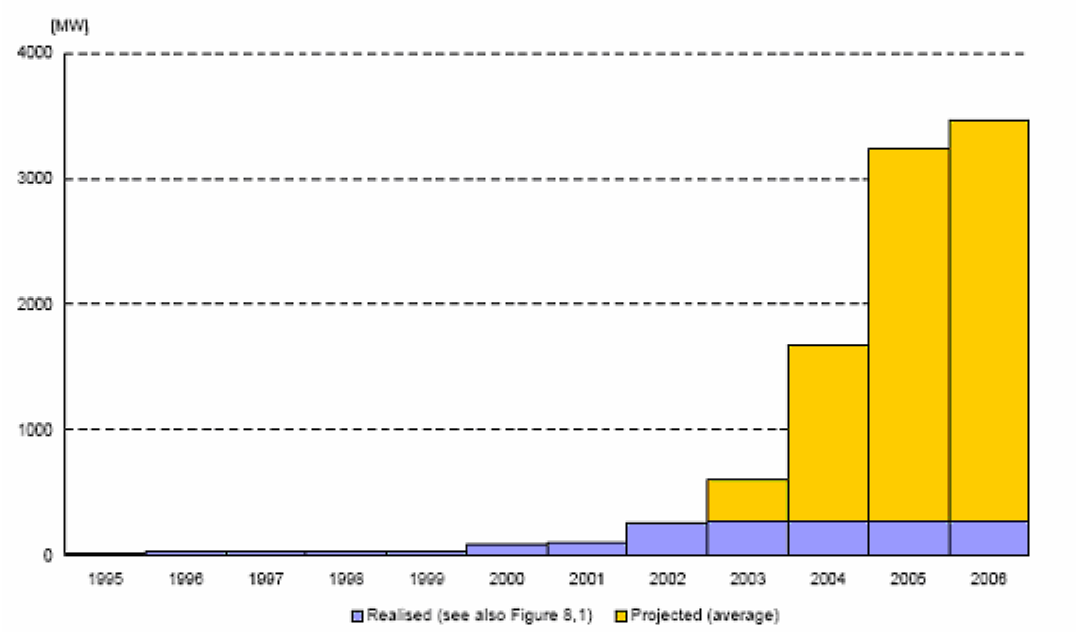


Figure 30: Future trends for realized and projected wind power

Apart from the move towards larger wind turbines there is also a move towards deep water offshore due to a number of factors. The most important factor is greater wind speeds that can be achieved at large distances from shore due to the low roughness factor of these areas, leading to high energy production if large wind turbines are used.

A graphical output showing this trend towards deeper water is shown in the figure below.

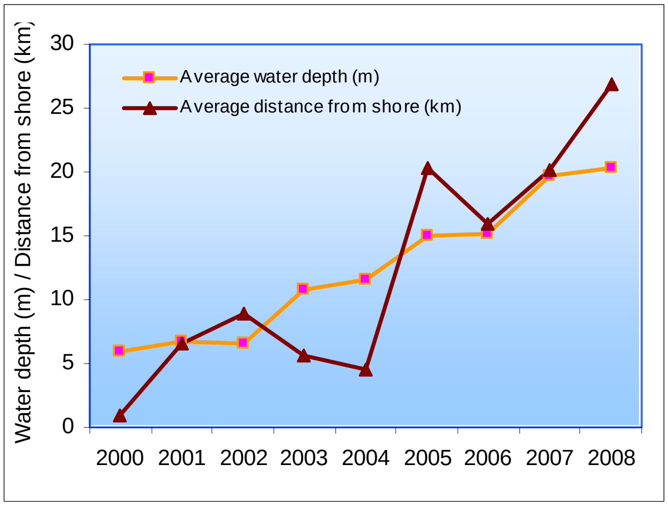


Figure 31: The future trend of moving to greater distances and water depths from shore

While striving towards greater water depths, apart from floating vessels and other floating foundations, monopile is the current solution.

Monopile can be placed at water depths of up to 15 m. From the figure below we can see that for greater water depths, the current solution until the time that floating foundations do exist, is the solution of using multiple piles(tripods) due to the lower cost of foundation as will be seen later on(figure 39).

Type of foundation	**Water depth**
Monopile	Up to 15m
Multiple pile(tripod)	Greater than 30 m
Gravity	All soil conditions-up to 50m
Floating	Up to 100m

Table 7: Type of foundation appropriate for each installation water depth

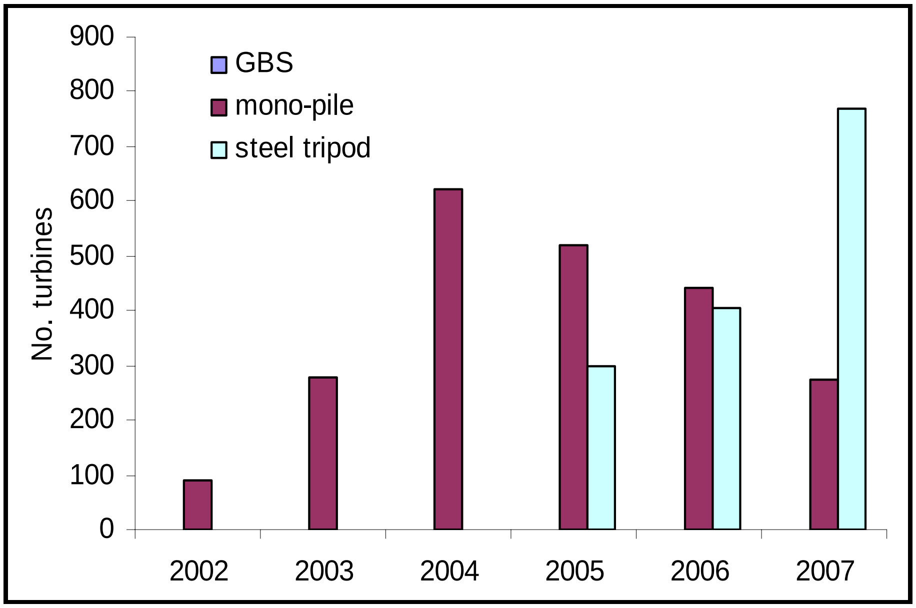


Figure 32: Current and future trend for the foundations of installed wind turbines

4. Connecting with the electrical grid

4.1 Connecting an offshore wind park with the grid

Future offshore wind parks, as everything shows, are expected to have much larger capacities of up to 1000 MW and to be located considerably further away from the coast. These wind farms must be connected to the grid by high or extra high voltage lines in order to minimize current and therefore losses. The installation point might be far away from the onshore electrical grid. The offshore wind farm can be connected with the mainland grid by a high voltage 3 phase A.C submarine cable if not far away from shore. In the case that the wind farm is far away from shore, high voltage D.C transmission lines (HVDCT) of 100 kV are used. In order to connect the offshore wind turbines to the shore, a submarine cable has to be laid down and the submarine cable length could be large enough depending on the morphology of the seabed, the distance between the wind turbines and the shore, and the water depth.

The most usual arrangement for connecting the offshore wind park with the onshore grid is presented in figure 33.

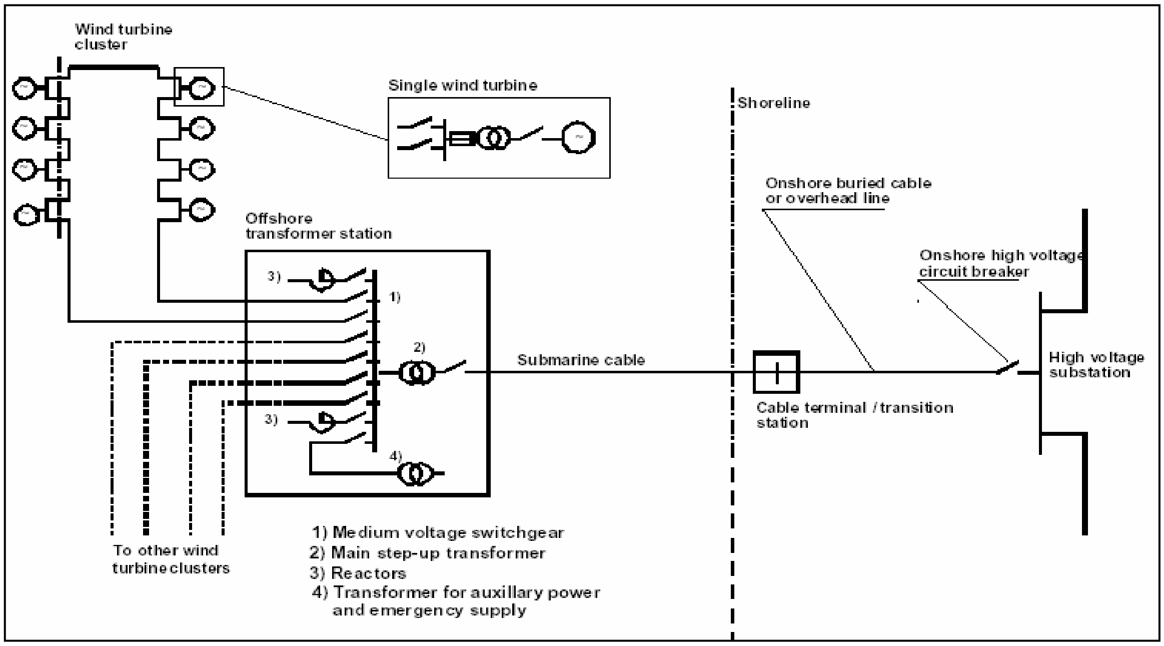


Figure 33: Connecting offshore wind turbines with the onshore electrical grid through a ringed network.[10]

As can be seen from the figure above, the wind turbine clusters are connected to medium voltage switchgear that can keep producing electricity even during maintenance periods, thus reducing the economic consequences in case of malfunction of the submarine cable. The choice of the right voltage level at the wind park is clearly dependent on the way the wind turbines are installed. Each wind turbine is equipped with a transformer having as a voltage input the one that the wind turbine produces. The transformer station is a construction that is based on pylons and is placed above the water surface. The transformer station increases the voltage at the right voltage stage for transporting energy to the connection point with the shore. This voltage stage depends on the size of the wind farm and can be from an average voltage to the maximum figure that can be used from the network, e.g. 400 kV.

Transportation of electrical energy is done through the submarine cable that can get damaged due to fishing boats and anchoring of boats. Depending on the weather conditions, repairs to the submarine cable can take several weeks causing production losses.

In figure 33 a ringed network is presented. Wind turbines can also be connected through a radial network as can be seen in figure 34. The radial network offers redundancy in case a cable failure occurs. The faulty cable can be replaced while the remaining wind turbines continue operating properly. With radial networks, failure of one section could lead to loss of production of several wind turbines. Investigations have shown that the loss of production for offshore wind farms on average is expected to amount to moderate 0.026% of the ideal annual energy production[16].

Thus radial networks are preferred because they provide a cost effective connection method for offshore wind farms.

During these periods, the voltage transmission between the wind turbines and the transformer station should continue for operational reasons, such as maintenance and cooling system operation at the wind turbines internal.

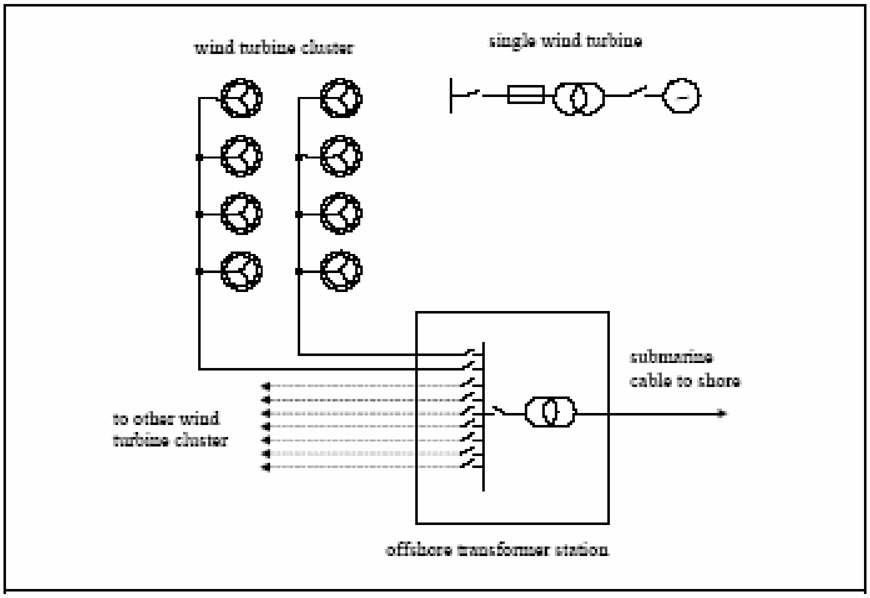


Figure 34: Connection of offshore wind turbines through a radial network[10]

According to a paper entitled ‘The role of HVDC Transmission in future energy development’ a break-even distance of approximately 50 Km is specified for offshore HVDC transmission lines[17].

In the event that high voltage A.C transmission lines are used, the cost is kept low because A.C transmission is a well-known technique that requires an offshore substation, the submarine cable and an onshore substation but it bears the disadvantage of high losses for large distances.

In the event that high voltage D.C transmission lines are used apart from the equipment needed for A.C transmission, additional equipment is needed such as phase shifters, rectifiers and inverters that increase the total cost of the wind farm and are economical only for large offshore wind farms placed at long distances from shore.

These submarine cables are usually buried in the sea bed and coated with lead and steel in order to become waterproof and withstand the extreme fatigue forces applied on them. This extra weight does not allow the submarine cable to move on the sea bed due to the water currents applied on them. There are four types of cabling that can be used and these are single or triple conductor oil insulated cables and single or triple conductor PEX (PolyEthylene) insulated cables.

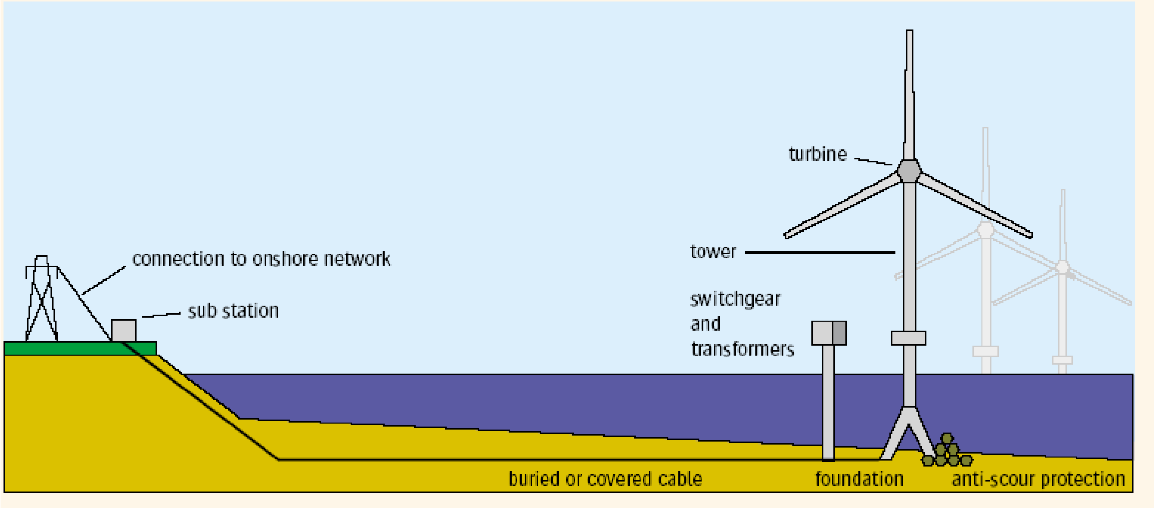


Figure 35: Graphical presentation of a wind farm connection with the shore

4.2 Grid Stability

Grid stability of the electrical network is very important since the percentage of the energy production from wind turbines keeps increasing. There are three main problems that have to be examined.

The first one is the problem of low voltage periods followed by periods of null power due to overloading of the network which interrupts the voltage flow balance at the connection points, resulting in harmonic problems. Although the capacity of the wind turbines is enough, there might be sudden voltage decrease. In that case, the power feedback will lead the operational voltage to its stability limits.

Pausing power production is the next important problem that has to be examined. In a case like that, if the power production units do not operate until the moment of power production pause at their maximum load in order to cover the power dissipation, a black out will occur. A way to solve this problem is to stop powering a unit until the power production level is restored.

The third problem which is also the commonest one is short circuits. Many of them are encountered from the circuit safeties by closing the circuit for a few milliseconds and then restoring the circuit. Large offshore wind parks can be shielded by disconnecting them selves from the electrical network in order to adopt a dynamic stability at the wind turbine grid which is essential for voltage lines equal and greater than 100kV.

4.3 Power production forecast

In the past, electrical network administrators had to face the stochastic character of electrical power demand. Nowadays, the use of wind turbines has raised the issue of stochastic electrical power production. For a percentage of penetration equal to 10% of the electrical energy produced from wind turbines, there is no problem for the national electrical grid. When this percentage increases, there should be appropriate electricity saving arrangements in order to balance the difference between power production and power demand. This problem can be solved using appropriate systems that can forecast the power production needs for a time period between three hours and up to two days later on.

These systems download data from climate forecasting models, data about the power production at the offshore wind park, and forecast the production of electrical energy. The above procedure is presented in figure 36.

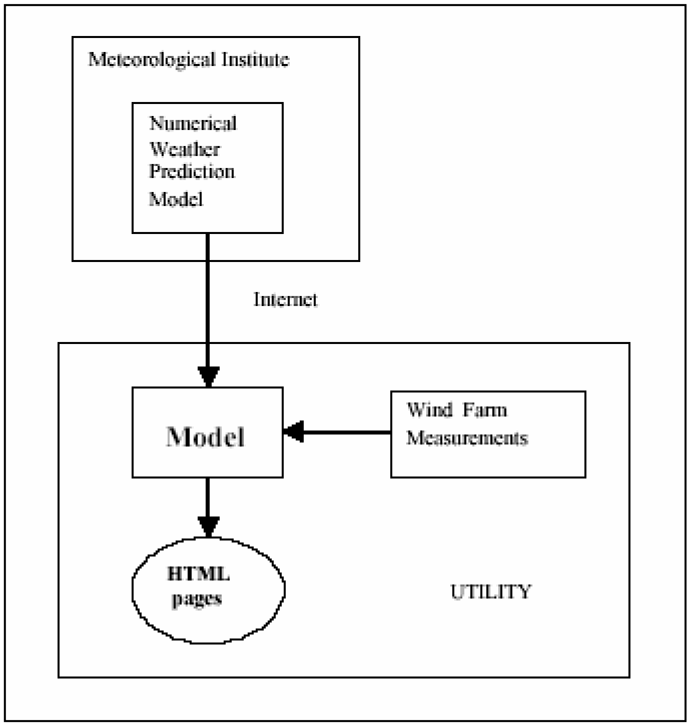


Figure 36: Models used for forecasting wind park power production[10]

Two of these models are the Riso and the IMM forecasting models which are considered to be the two best ones in the world at this time.

Model Riso was created by the equivalent National Research Center of Denmark and IMM was developed by the Institute of Mathematical Modelling Of Denmark.

5. Environmental impacts

Although wind energy is a clean source of electricity, during the construction, operation, maintenance and decommissioning of the offshore wind turbines of a wind park, pollution is created either in the form of physical pollution such as noise and visual impact or pollution such as waste material and sea pollution. Before constructing a wind farm, the wind farm owner has to produce an environmental impact assessment (EIA) presenting all kinds of impacts that might be created at the specific site of installation. The extent of site investigation will be highly dependent on the specific location and varies considerably from site to site.

The project elements usually considered are the following ones:

- Manufacture of the foundations, towers, nacelles, blades and turbines
- Transportation of the above materials to the port and transportation from the port to the specific site for installation
- Installation of the wind turbines including foundations and pylons
- Installation of cables between the facilities and the shore
- Operation and maintenance of the turbines
- Decommissioning of the foundations and the turbines

In this section the operation and maintenance stage will be mainly considered but the impacts of all stages will be concisely presented.

5.1 Manufacturing impacts

Starting from the manufacturing stage, first of all it is worth mentioning first of all the positive impact of job creation, especially during the manufacturing and assembly stages. Employment is created in all stages but mainly more personnel are needed at this stage. The negative impacts are the temporary localized disturbance due to noise and gaseous emissions, and the creation of waste materials from the production of the equipment needed for the wind farm to operate.

5.2 Transportation impacts

Transportation impacts include the emissions created in order to transport the raw materials to the turbine assembly factory, in addition to the emissions created in order to transport the wind turbines components to the shore, in order to be transported to the specific site of installation. There are also localized impacts due to the method of transport of the equipment to the factory and to the shore. The use of train and boat for example creates only emission impacts but the use of lorries creates both emissions and physical impacts on the other drivers due to the increased traffic and other problems created due to this means of transportation.

5.3 Installation of the wind turbines

The impacts that the installation of the wind turbines have in general, mainly depend on the type of foundation. For example when using monopile foundations no sea bed preparation is required. However, for steel gravity foundations, sea bed preparation is required, creating greater impacts on the environment.

Vessels associated with the work may lead to temporary disturbance effects. The physical presence of vessels creates visual disturbance effects, but it can also force fishermen or the shipping industry to stop using the area around the construction vessels during the works or even after the end of the installation works.

Another impact that the vessels can have is sea pollution such as oil from accidental collision between vessels.

Installation of the turbine foundations can cause loss of marine life and habitat either directly or indirectly from smothering or clogging of benthic organisms by disturbed sediments. The importance of these effects depends on the ecosystem and the sea bed of the specific area and differs from site to site.

Underwater noise created during the foundation work such as drilling or hammering, or due to the operation of the wind turbine such as the noise frequency, and the sound power level, may result in creating a poor fishing area.

Excavated materials abandoned at the area of installation of the wind turbines deposited on the sea bed, can cause severe changes to the morphology of the seabed and the water depth.

The installation of the remaining wind farm components onto the foundation will cause small disturbance effects but mostly side effects such as visual intrusion. The first visible structures are the ones that usually create the first impression and can cause either the rejection or acceptance of people. There are a number of important factors that should be considered when designing an offshore wind park, such as informing people through photomontage pictures of what is about to be constructed, showing the visual intrusion that the wind park is going to create, or even making a visual impact assessment to identify a number of preferred wind farm designs and footprints.

5.4 Cable installation

Cable installation can be done in a number of ways such as anchoring, jetting, washing or trench excavation, each of which has different impact weightings. Cables are buried for protection and to prevent them from being a physical obstacle to anchoring and fishing. Areas laid down with cables may not be available for shipping or for sea leisure activities. Installation of the cable can cause disturbance to marine organisms and coastal activities. Any potential effects on the local environment and the rare species that might exist in that environment should be considered from the beginning by being given authorization for installation from the environmental agency and the local authorities. Once the cables reach the shore, they can be either buried or placed on overhead transmission lines which is a common technique and has been used in the past, resulting in known impacts such as the possibility of electric shock if a line is damaged and visual intrusion.

5.5 Operation and maintenance of the turbines

Operation of wind turbines has only positive effects on the environment because the use of renewable sources of energy is an important way to reduce the gaseous emissions of CO_2, NOx, CO, CH_4 and many others.

In table 8 you can see the CO_2 emissions created in tonnes per GWh during the life cycle of many different sources of energy.

Source	**Fuel Extraction**	**Construction**	**Operation**	**Total**
Coal-fired	1	1	962	964
Oil-fired	-	-	726	726
Gas-fired	-	-	484	484
Nuclear	~2	1	5	8
Wind	N/A	7	N/A	7
Photovoltaics	N/A	5	N/A	5
Large hydro	N/A	4	N/A	4
Solar thermal	N/A	3	N/A	3
Wood	-1509	3	1346	-160

Table 8: CO2 emissions in tonnes per GWh from different sources of energy[11]

What can immediately be understood from the table above is the size of reduction of the CO_2 emissions created from wind in comparison with common thermal energy production methods. The best way in order to study and compare the environmental consequences is through a Life Cycle Assessment (LCA), which can calculate all the consequences of a product on the environment during its life cycle, which means that LCA examines the production, the use, and the dismantling of this product. This study has not yet been carried out for offshore wind parks but only for onshore ones. LCA for onshore wind parks showed that the energy that is used for the production, operation, maintenance and dismantling of a wind park is usually produced from the wind park at a period of three months after commissioning.

5.6 Physical presence of a wind turbine

The physical presence of a wind turbine also has its own effects. First of all, wind turbines are a physical obstacle to fishermen, shipping, navigation, even to aircraft and in general to all the sea and sky users in close proximity to a wind park. There is also the eye-catching effect of the blade movement itself and this is the reason that most wind turbines blades are colored in order not to attract our attention.

5.7 Electromagnetic interference

Wind turbines can also cause interference to microwave signals such as telecommunication networks if the turbines are located in line with transmitter and receiver path links. Blade rotation can cause interference with radar installations. The turbines can appear as genuine aircraft targets, or may degrade the radar performance, causing confusion about the height or the distance of an object from the radar.

5.8 Interference with ships

Full details on the turbines location and the change of the sea bed or the water depth should be given to mariners in order to prevent the case of ship collision leading to casualties, or in the best case, pollution of the water from diesel and oil.

5.9 Sea bed morphology

Local erosion or deposition around the base of the structure can lead to sea bed morphology change or even collision of two or more wind turbines together. For this reason wind turbines are located at a distance between them, which is approximately equal to ten times the diameter of their structure. Local water movement should be considered when designing an offshore wind park and especially if the foundations are going to be placed on sandbanks whose stability is insecure.

5.10 Impacts on birds

Biological impacts on birds concern possible negative impacts of offshore wind parks on the vital organisms that live or visit the area of the wind park. There are three main parameters that are examined during the construction period. Possible bird collision with the pylon or the blades of the wind turbine, the disturbance during the construction period and the vitiation of the birds’ natural environment that can lead to bird migration to another area. Offshore wind farm construction and operation experience has shown that the first two parameters are not so important. Studies that have been carried out at the offshore wind parks of Tuno Knob in Denmark and Utgrunden and Yttre Stemgrund in Sweden concerning the species of Eider duck, have shown that their population increases and decreases according to the sea food available and that ducks have no problem avoiding the wind turbines. The same study showed that ducks understand the presence of the wind turbines from a distance of 3 to 4 Km away, even during night time, and accordingly change their route thus maintaining a safe distance of about 1 km away. As for the third parameter, that is the vitiation of the natural environment, it can be solved by prohibiting potential installation areas that are protected and are important for birds or immigration paths.

5.11 Impacts on sea mammals

Water born noise and vibration transmitted from the rotating blades through the tower and into the water can cause disturbance to sea mammals. Sea mammals rely on sound in order to understand their environment, to sense food and to communicate. Disturbance depends on the sensitivity of the sea mammals and the frequency range of the emitting noise. Actual measurements of underwater noise generated by offshore wind parks (frequency and sound power level) have shown that they do not actually have a great impact on sea mammals such as the studies for the sea mammals of Bockstigen and Tuno Knob wind parks.

Apart from the emitting noise of the wind turbines, underwater sea cables might also be a source of emitting noise. Research that has been done for an underwater sea cable buried one meter below the level of the seabed, showed that the magnetic field of the cable is lower than that of the earth, so there is no point for extra studies to be carried out.

5.12 Biological impacts on fishes

Fishes can be affected by noise or vibration which might lead them to permanently move away from an area. Studies have shown that concrete gravity foundations act as an artificial reef helping flora and fauna to provide food and protection for fishes. Prohibition of fishing at offshore wind farms will help to increase the fish population and will provide them with an exceptional environment for reproduction and development.

5.13 Impacts on humans

Noise from the wind turbines is emitted mainly through air and water. The impact on humans depends mainly on the type and level of the emitted noise, the distance between the human and the noise generating equipment, the wind direction and any barriers that might lead to the attenuation of the noise. The level of noise mainly depends on the type and point of installation of the wind turbine but is generally much lower than the noise generated from road traffic or trains. Careful design and manufacture of the blades together with insulation at the gear box and generator reduces the noise created at minimum level.

The most important consequence on humans is the negative impact of the view of a wind turbine at a sea environment. Experience until now has shown that human reaction is negative at the beginning of the construction, gradually people become accustomed to visual intrusion of the wind turbines. Wind parks can also be seen as a tourist attraction and this is the reason why the Mayor of the city of Nysted of Holland which is next to Rodsand wind park, demanded that the name of the wind park be changed and renamed as ‘Offshore wind park of Nysted’.

5.14 Environmental impacts due to accident

An accident between a ship and an offshore wind park might have terrible consequences for the ship, for the wind park and for the wind park’s close environment. Although there is a small possibility of having a ship collision with a wind turbine, the consequences are severe. For example, a ship collision between a tanker and the transformer station will lead to the loss of millions of Euros due to the damage to the wind turbine, the fines that the operator will have to pay and the loss of electrical energy. It is obvious that oil leaks from a tanker will have the greatest impact on the environment.

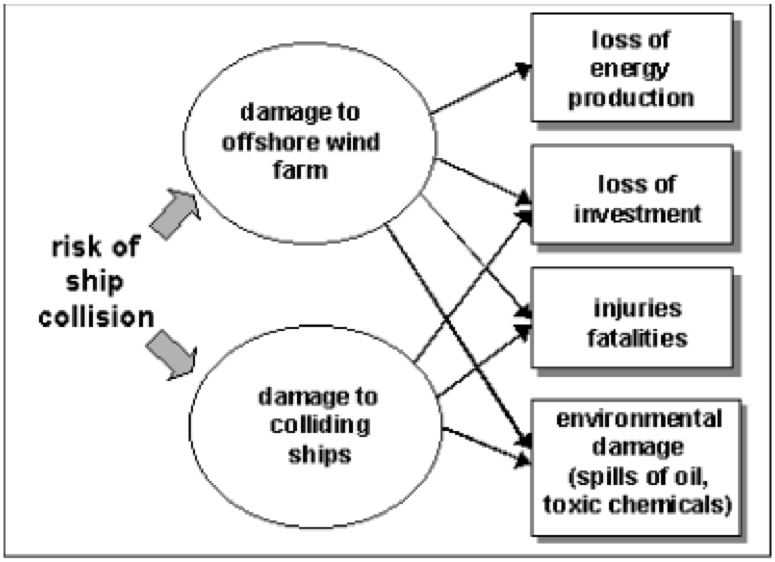


Figure 37: Ship collision risks[11]

5.15 Decommissioning

When complete decommissioning of the wind farm is required, the wind turbine foundations have to be either pulled or severed below the seabed. In the case of monopile foundations, they must be terminated at least three meters beneath the ground.

Underwater sea cables also have to be removed. These activities will lead to the creation of vibrations and noise but significantly lower than the noise created when the wind farm was at construction phase. The greatest impact is the one on fishes. Because the wind turbine foundations usually have a 40 to 50 years service life cycle, their decommission will cause removal of the colonizing organisms, although over time they will return to the initial conditions. Removal of the wind farm might allow commercial fishing to recommence in areas where fishing was previously prohibited, based on the fact that during these 50 years of operation, fish diversity and productivity will be increased, so removal of the wind farm will have minor effects on fishes.

The removal of the wind turbines will cause similar disturbances for sea birds, forcing them to migrate for a while although they will return to their normal conditions a few days after decommissioning has ended.

Decommissioning might lead to sea pollution due to the waste material that might be left behind at the place of installation of the wind farm, resulting in sea bed and water depth alterations.

All of the above can be minimized by carrying out an environmental impact assessment during the design stage of the proposed wind park, leading to fewer impacts at the end of the life cycle of the wind park.

6. Worldwide offshore wind status and development

6.1 Development in European Union (E.U) Countries

E.U countries, especially the ones from Northern Europe, lead the offshore wind energy sector. In 2003 in Madrid the EWEC (European Wind Energy Council) conference was held, where it was concluded that by 2010 there are going to be installed offshore wind parks of a total energy output of 10000 MW and by 2020 the total energy output will reach 70000 MW.

In the following paragraphs, the countries that develop offshore wind energy actions, their offshore wind parks in operation and the offshore wind parks that are under construction at this stage are noted.

6.1.1 Sweden

Sweden was the first country that installed offshore wind turbines and as presented in the table below, by the end of this year it is anticipated to have 7 offshore wind parks of a total power output of 204.72 MW.

Name	**Electrical power production of park(MW)**	**Current status**	**Year**
Nogersund	0.22	Operational	1990
Bockstigen	2.5	Operational	1998
Utgrunden	10	Operational	2000
Yttre Stengrund	10	Operational	2001
Klasarden	42	Under Construction	2003
Lillgrund Bank	86	Under Construction	2003
Skabbrevet	54	Under Construction	2004
Total	**204.72**		

Table 9: Offshore wind parks in Sweden

Eleven further projects are planned, mainly by Airicole company, such as Utgrunden phase 2, most of them having the year 2008 as an operational target.

6.1.2 Denmark

Denmark is the most energetic country in the field of offshore wind energy and this is due to its ground morphology and the ecological sensitivity of its population. Following the "Action Plan for Energy, Energy 21" the government of Denmark intends to have a total power output from offshore wind parks equal to 4000 MW installed by 2030. When this action plan has been completed, Denmark will cover 50% of its electricity demand from wind energy. The total investment for the construction of these offshore wind parks will be approximately 7 billion Euros, which is the largest investment ever made worldwide for the construction of offshore wind parks.

Table 9 presents the current and future status of Denmark in the offshore wind energy field.

Name	**Electrical power production of park(MW)**	**Current status**	**Year**
Vindeby	4.95	Operational	1991
Tuno Knob	5	Operational	1995
Middengrunden	40	Operational	2000
Samso	23	Operational	2002
Horns Rev	160	Operational	2002
Frederikshavn	10.6	Operational	2003
Nysted	158	Under Construction	2003
Total	**401.55**		

Table 10: Offshore wind parks in Denmark

The Danish government's decision to cancel its support for the next three large offshore wind parks of Laeso, Omo Stalgrunde and Nysted phase 2, has been reversed to the extent that a tendering process has been examined for each of them and bidding is scheduled to start by the end of this year.

6.1.3 Holland

The government of Holland has set as a target a reduction in the consumption of natural resources by 10% by 2020.In order to achieve this target it is calculated that wind parks of a total power output of 3000 MW have to be installed, of which half will be offshore ones.

Name	**Electrical power production of park(MW)**	**Current status**	**Year**
Lely	2	Operational	1994
Irene Vorrink	16.8	Operational	1997
Near Shore Windpark (NSW)	100	Under Construction	2005
Q7-WP	120	Under Construction	2005
Total	**238.8**		

Table 11: Offshore wind parks in Holland

6.1.4 France

France is one of the countries whose energy production is based on nuclear plants and not wind power. At the current moment France is constructing its first wind park as can be seen from the table below.

Name	**Electrical power production of park(MW)**	**Current status**	**Year**
Breedt/Mardyck Bench	8	Under Construction	2003
Total	**8**		

Table 12: Offshore wind parks in France

6.1.5 Germany

Germany is due to dynamically enter the field of offshore wind energy with offshore wind parks either scheduled or under construction of a total energy output of 1424.5 MW as can be seen from table 13. Particular attention should be paid to Borkum West offshore wind park which at its final stage will be able to provide Germany with 1040 MW.

Name	Electrical power production of park(MW)	Current status	Year
Mecklenburg-Vorpommen	40	Scheduled	2003
Jade	4.5	Under Construction	2003
Borkum West	1040	Under Construction	2004
Sky 2000	100	Scheduled	2004
Butendiek	240	Scheduled	2005
Total	**1424.5**		

Table 13: Offshore wind parks in Germany

Germany's way of thinking is based on the premise that by the time these enormous projects are ready to progress, industry, associated technologies and market mechanisms will be ready to make them successful. Germany will have to wait until the end of 2004 to see the installation of the first true multiple turbine development. At the current moment Enercon has installed its giant 4.5 MW prototype in the Jade estuary and it is being tested and further developed.

6.1.6 The United Kingdom

At the current moment, the U.K has only two offshore wind parks at an operational stage with a total power output of 100 MW, but over the next two years there is going to be a massive increase in the total energy output from offshore wind farms. None of the other thirteen countries with planned projects have so many projects approved. The Government is trying to help potential developers by subsidizing them with significant government grants (14 million pounds on average). The UK will emerge as one of the world leaders in offshore wind in the near future.

As is presented in table 14, if no further delays hinder the projects, the total power output of offshore wind parks by the end of 2005 will be equal to 1382 MW.

Name	Electrical power production of park(MW)	Current status	Year
Blyth	4	Operational	2000
Kentish Flats	80	Approved	2003
North Hoyle	60	Operational	2003
Gunfleet Sands	108	Approved	2004
Inner Dowsing	120	Approved	2004
Barrow-in-Furness	90	Approved	2005
Solway Firth	180	Approved	2005
Moray Firth	500	Scheduled	-
Cromer	120	Approved	2005
Scarweather Sands	90	Under approval	2005
Burbo	90	Under approval	2005
Total	**1382**		

Table 14: Offshore wind parks in the United Kingdom

6.1.7 Ireland

Ireland has scheduled the construction of one new offshore wind park whilst Arklow Banks offshore wind park is half operational providing the grid with 25.2 MW which is the first phase of a 520 MW wind farm.

Name	Electrical power production of park(MW)	Current status	Year
Arklow Bank	25.2 (520)	Operational	2003
Kish Bank	250	Scheduled	2003
Total	**770**		

Table 15: Offshore wind parks in Ireland

6.1.8 Belgium

For the time being, Belgium has only one wind farm operating which is in Zeebruge port and consists of 14 wind turbines situated on a dam. Recently, the Belgian Council of

State, forbade the continuation of Seanergy project of a total power output of 100MW due to complaints regarding the granting of permission.

Name	**Electrical power production of park(MW)**	**Current status**	**Year**
Seanergy	100 MW	Scheduled	2003-2004
Zeebruge	28	Operational	2003
Fina-Eolia	100(180)*	Scheduled	Unknown
C-Power	100	Permission refused	
Zephyr	300	Scheduled	Unknown
Thornton Bank	216(300)**	Scheduled	2005
Total	644(808)***		

*From 100 to 180MW dependent on the approval

**From 216 to 300 depending on the wind turbines that are going to be used

***Final total depending on the Fina-Eolia and Thornton Bank projects

Table 16: Offshore wind parks in Belgium

6.1.9 Finland

Four offshore wind parks are planned near Helsinki that are going to use 15 to 20 turbines of 3 MW each. The final number of wind turbines used depends on whether government support will be granted or not.

Name	**Electrical power production of park(MW)**	**Current status**	**Year**
Helsinki	180(240)*	Scheduled	Unknown
Total	180 to 240		

*180 to 240 MW depending on the final number of wind turbines used

Table 17: Offshore wind parks in Finland

6.1.10 Poland

The first offshore wind park is expected in the region of Bialogora near the city Slupks, totalling 61 wind turbines from two to three MW each. The start of installation is expected in 2004.

Name	Electrical power production of park(MW)	Current status	Year
Slupks	122(183)*	Under Approval	2004
Total	122 to 183		

*122 to 183 MW depending on the number of 2 MW and 3 MW wind turbines that are going to be used

Table 18: Offshore wind parks in Poland

6.1.11 Spain

One offshore wind park, the Cabo de Trafalgar in the Atlantic Ocean is to be developed in two phases using wind turbines with a total output of 250 MW. Installation is to start by 2004 and end by the end of 2005.

Name	Electrical power production of park(MW)	Current status	Year
Cabo de Trafalgar	250	Approved	2004
Total	250		

Table 19: Offshore wind parks in Spain

6.1.12 Rest of E.U countries

For the rest of E.U countries such as Italy, Greece, Norway and Portugal there is no information yet on planned offshore wind parks.

6.2 Development of offshore wind energy outside Europe

Outside the E.U precincts there are no offshore wind parks under operation although there are a number of areas that fulfil the needed conditions for construction offshore wind parks in the U.S.A, Canada and China. Regarding the for the United States, most proposals concern floating wind turbines that are going to be located at areas of great water depths of up to 100 m and at distances from shore above 10 Km.

Name	**Electrical power production of park(MW)**	**Current status**	**Year**	**Country**
Cape Wind	468	Under Approval	2004	USA
Long Island	140	Proposal	2004	USA
Nai Kun	680	Proposal	2004	Canada

Table 20: Non E.U offshore projects

7. Economic and technical data

7.1 Cost data for offshore wind parks

The cost of developing an offshore wind farm is very high especially due to the high cost of foundation and connection with the electrical grid. As for the cost of operation and maintenance, the data until now does not allow precision for a long term basis. In figure 38 there is a graphical presentation of a typical cost analysis for a 150 MW offshore wind park.

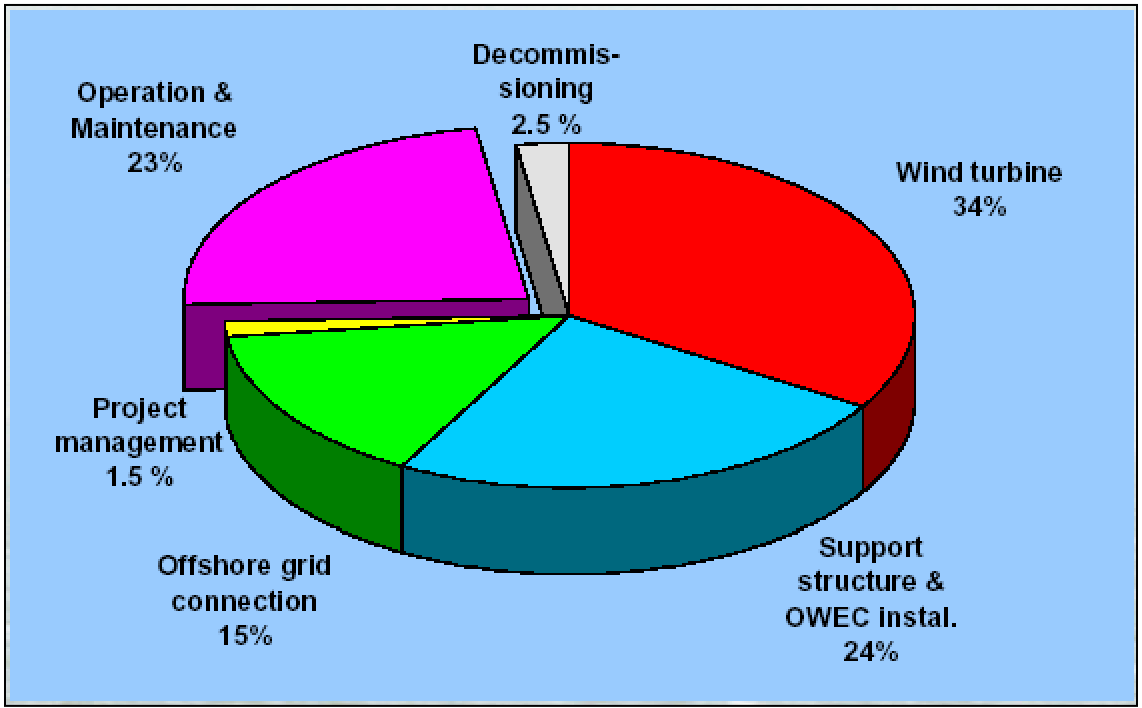


Figure 38: Typical cost analysis for a 150 MW offshore wind farm[7]

As can be seen from figure 38, 39% of the total cost comprises the foundation cost and the cost of electrical connection. Although this data is valid for a typical offshore wind park of 150 MW, in the next paragraphs similar graphs for onshore and offshore wind parks, based on the most recent data taken from Danish wind farms are going to be described

There are a number of factors that combine in order to increase the cost of offshore wind farms above onshore costs.

Firstly, the grid connection cost. The cost of the cable for connecting the wind turbine with the shore increases with the distance from shore and accounts for between a 17 to 34% increase of the total cost.

The next reason that leads the cost to increase is the need for more expensive foundations. The cost of the foundation increases with water depth and can account for up to 30% of the total cost.

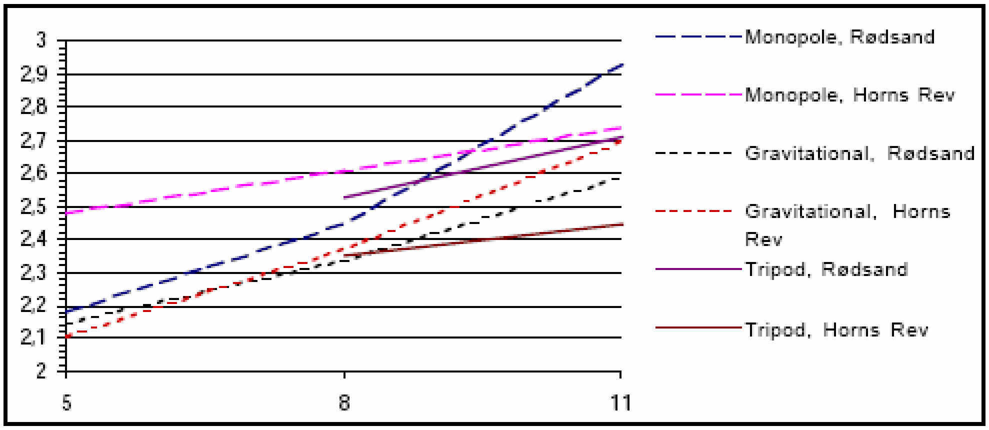


Figure 39: Cost (in DKK) of offshore wind turbines foundation by water depth (in m)[12]

Due to the marine environment that the wind turbines are located in, there is a need to 'marinise' the wind turbines in order to protect them from the corrosive influence of salt. These needs can increase the cost of up to 20% more than the normal turbine cost.

Finally, there is a need for the foundation of the wind turbine to have a life of 50 years and 25 years for the wind turbine itself. Due to the marine environment, maintenance can be difficult and costly. So there are increased operation and maintenance costs due to the risk of lower maintenance availability because of bad weather.

At this point, it is worth mentioning the trend towards reducing the cost of installation and as a consequence the cost reduction of producing energy from these sources.

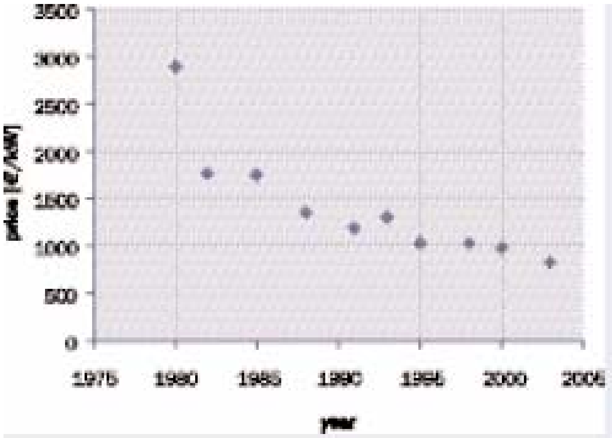


Figure 40: Wind turbine price reduction per year[10]

From the figure above it is obvious that in 2003, the price of an onshore wind turbine was reduced from approximately 3000 Euro/KW to 870 Euro/KW due to the knowledge and the experience gained and the standardization of the production of wind turbines.

To sum up the increase in cost of the wind turbine due to the distance from shore, the following table shows the additional investment expenses needed for the foundations, the installation, the grid expenses, in addition to other expenses that are needed as a percentage of the wind turbine price. It can be seen that for foundations located 30 Km away from shore there is a cost increase of 35.3 to38.2 % while for foundations 70 Km from shore, the additional cost to a wind turbine of 870 Euro/KW is from 38.8 to 47.5 %.

Distance from shore	**30 Km**	**50 Km**	**70 Km**
Foundation costs increase	35.3%-38.2 %	43.5 %-51.2 %	38.8 %-47.5 %
Installation cost increase	8.8 %- 13.3 %	10.9 %-18.5 %	9.7 %- 23.3 %
Grid connection cost increase	31.2 %-67.2 %	44.3 %-82.8 %	57.2 %-113.5%
Other expenses increase	7.4 %- 23.9 %	7.4 %-23.9 %	7.4 %-23.9%
Total additional expenses	***82.7 %-142.6%***	***106.1 %-176.4***	***113.1 %-208.2 %***

Table 21: Additional investment expenses as a percentage of a wind turbine (870 Euro/kW) in relation to the distance from shore.[10]

During the period when the first offshore wind parks were installed, their difference with onshore wind parks was tremendous, so there was no scope for designing wind parks for merchant exploit. But after a few years, the cost is decreasing continuously as can be seen in figure 41 in which the cost of energy produced in Euro/KWh is presented for a time period equal to 10 years for parks that are under development and construction or even operational at that moment. In order to be more specific, for the first offshore wind park in Denmark (Vindeby) in 1991,the cost of electricity production was 2200 Euro/KW. Seven years after Bockstigen offshore wind park was constructed (in 1998), the cost of electricity production was 1880 Euro/KW. For the most recent offshore wind park, Horns Rev, which is the largest offshore wind park in the world, the cost of electricity production was equal to 1650 Euro/KW, which is equal to 0.049 Euro/KWh.

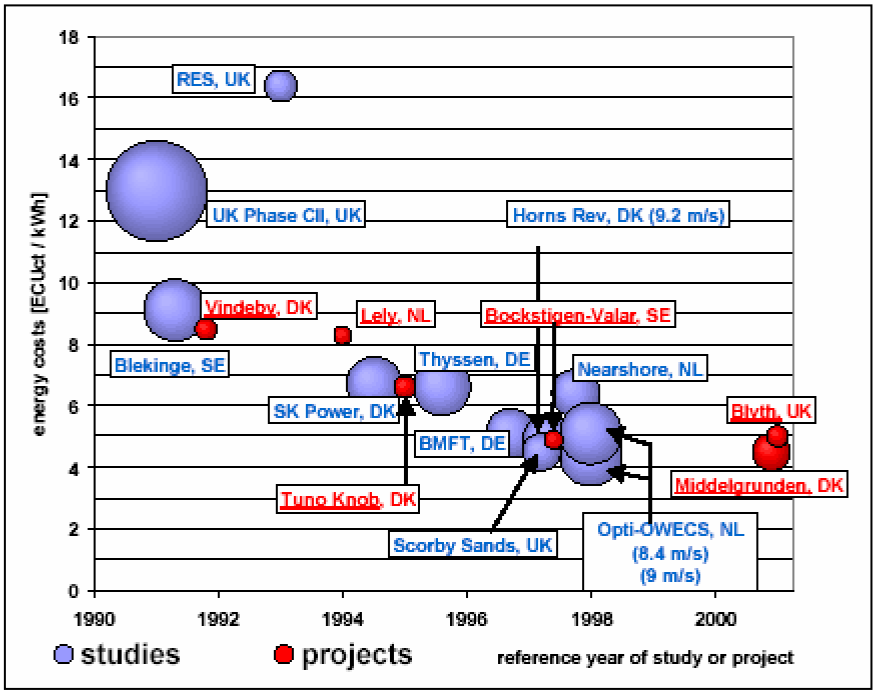


Figure 41: Cost of produced energy for both operational and under construction offshore wind parks[7].

7.2 Cost comparison between onshore and offshore wind parks

As was previously mentioned, offshore wind parks need higher capital costs in comparison with onshore ones and this is due to the high foundation cost and the cost of the electrical connection. In figure 42 there is a graphical cost analysis that arose came up from data collected from Danish offshore wind projects and in figure 43 the cost for onshore wind parks in Denmark can be seen.

As can be seen from figures 42 and 43 the percentage cost for the electrical connection of an offshore wind park with the grid is approximately 18%, which is much greater than the cost of electrical connection of an onshore wind park. Other sources that increase the final cost of an offshore wind farm are the foundation cost and the maintenance cost. It is worth mentioning that the above wind parks are located at a distance of 10 Km offshore and are installed in water depths of between 5 to 10 meters.

When the distance increases, the cost also increases as can be seen from figure 44. Figure 44 shows the cost increase versus the distance from shore for four offshore wind parks of 7.5,30,100 and 200 MW. It is obvious that the distance contributes positively to the cost increase but when the size of the wind park increases, the grid connection cost decreases.

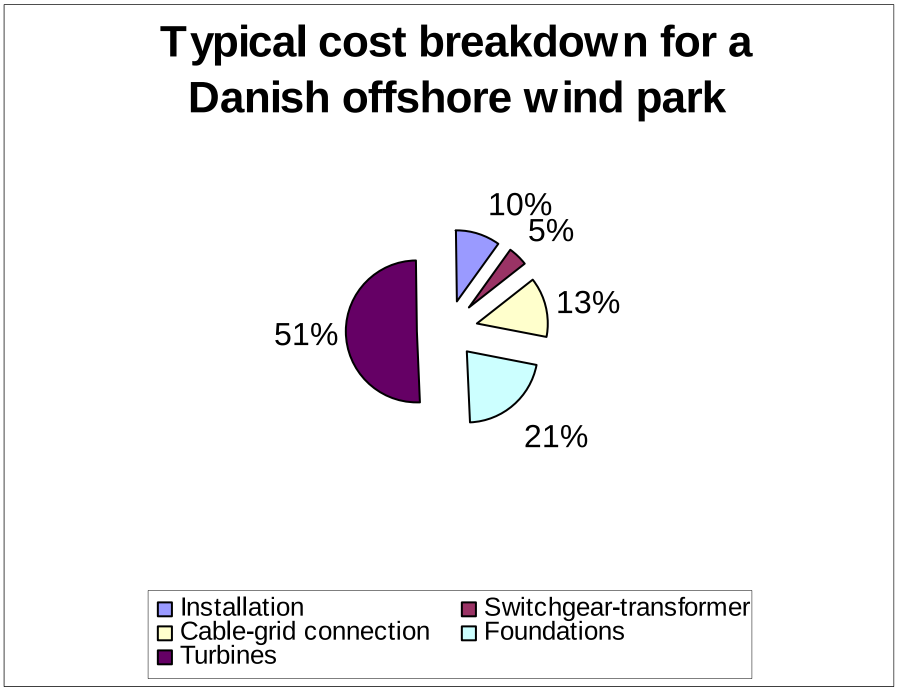


Figure 42: Cost analysis for a Danish Offshore wind park

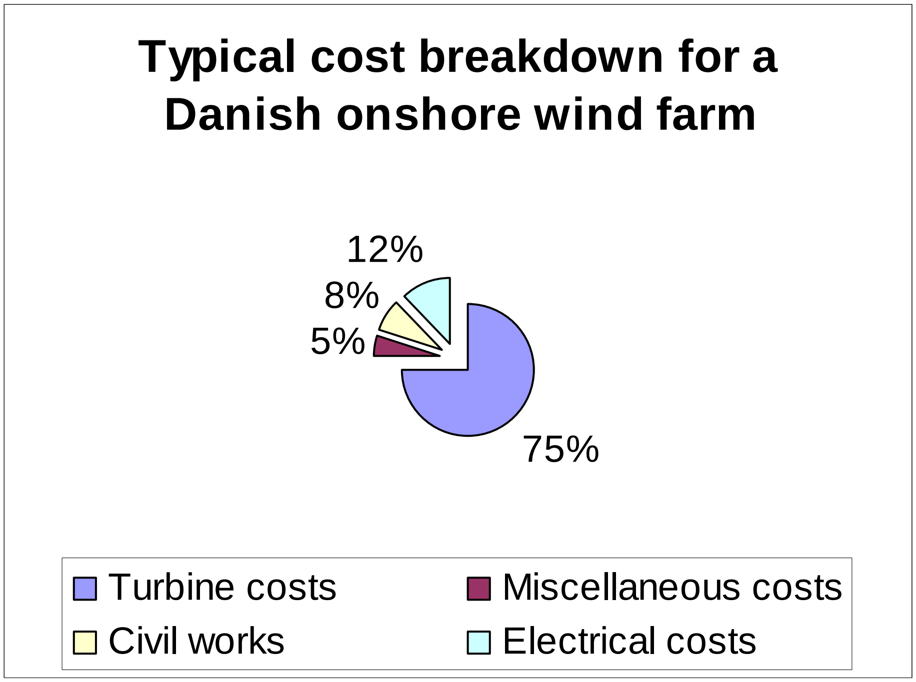


Figure 43: Typical cost breakdown for a Danish onshore wind farm

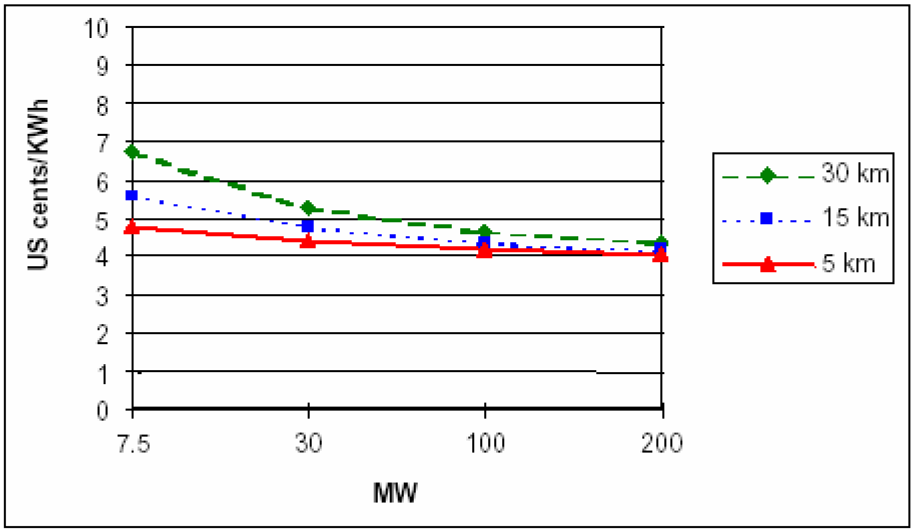


Figure 44: Increase of power production cost against the distance from shore for four different wind farms of 7.5,30,100 and 200 MW.

7.3 Ways of reducing the cost

As was previously mentioned, the main reason for the high cost of offshore wind parks is the foundation cost. A way of reducing the cost is with the use of multi-Megawatt wind turbines and this is because the two main parameters that define the needed durability of the wind turbine and the foundation weight are wave loading forces and ice loading forces. Therefore, it is more economical to use multi-Megawatt wind turbines because the size and the cost of the foundation does not increase according to their size.

Another reason for the total cost growth is the cost of electrical connection where it is obvious that it is advantageous to place fewer wind turbines for a specific size of wind park.

As a consequence of the above, it is advantageous to use wind turbines that have a high rated power output, e.g. for a wind park of 20 MW to use four 5 MW wind turbines instead of ten 2 MW wind turbines.

The development of new technologies in the field of electrical and electronic equipment will help to reduce the cost and increase the output of offshore wind parks. One of these new technologies is new transistor technology which does not require, in comparison with traditional thryristor technology, the need for D.C current on the two sides of the cable for transporting electrical energy, in order to change the current from A.C to D.C.

Research in the foundation field suggests the use of alternative solutions of lower cost, such as the use of steel gravity bases in addition to concrete gravity bases which can lead to a cost reduction of approximately 35%.

8. Horns Rev offshore wind park

8.1 General information of Horns Rev offshore wind park

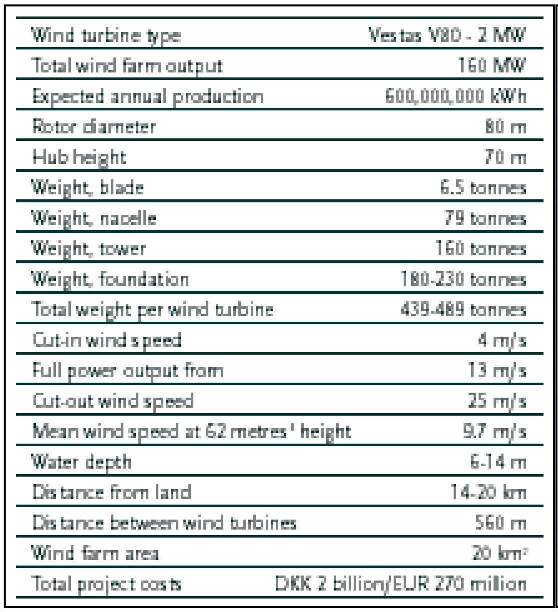
Horns Rev offshore wind park is the greatest offshore wind park in the whole world at this moment. It is a part of ‘Energy 21’ action plan which has the target of installing offshore wind parks that have a total output of 4000 MW. In February 1998 the Ministry of Energy of Denmark assigned to two companies, Elsam and Eltra, the construction of two offshore wind parks of a total output of 300 MW. The first one is the Horns Rev offshore wind park and the second is Laeso offshore wind park.

Horns Rev site is at a distance between 14 and 20 Km south-west of the region of Blavands Huk as can be seen in figure 45. 80 offshore wind turbines are installed at a grid of 8 lines having 10 wind turbines each and the water depth at the specific site varies from 6 to 14 m.

Figure 45: Horns Rev offshore wind park installation area

8.2 Type of wind turbines

The wind turbines that were chosen for the specific site are Vestas V80 type having a rated output of 2 MW each and their main characteristics are presented in table 22. The wind turbines of the specific site are positioned in a way that they form a parallelogram with side lengths of 5.06 km and 3.92 km, leaving a distance equal to 560 m between each wind turbine.



Wind turbine type	Vestas V80 - 2 MW
Total wind farm output	160 MW
Expected annual production	600,000,000 kWh
Rotor diameter	80 m
Hub height	70 m
Weight, blade	6.5 tonnes
Weight, nacelle	79 tonnes
Weight, tower	160 tonnes
Weight, foundation	180-230 tonnes
Total weight per wind turbine	439-489 tonnes
Cut-in wind speed	4 m/s
Full power output from	13 m/s
Cut-out wind speed	25 m/s
Mean wind speed at 62 metres' height	9.7 m/s
Water depth	6-14 m
Distance from land	14-20 km
Distance between wind turbines	560 m
Wind farm area	20 km²
Total project costs	DKK 2 billion/EUR 270 million

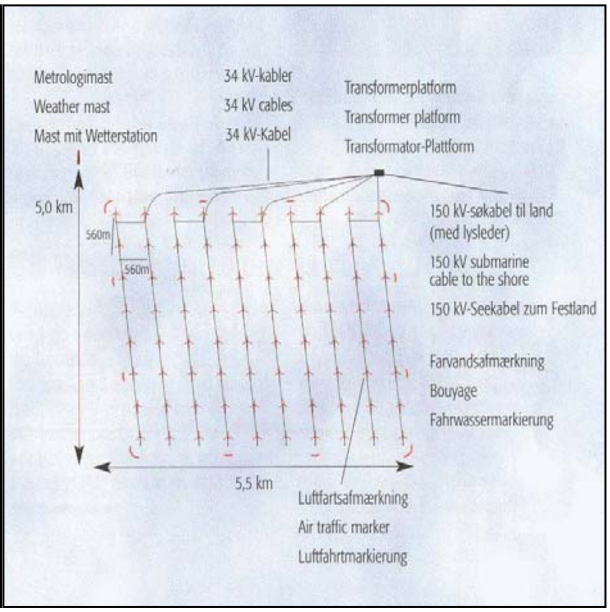


Table 22: Main characteristics of Horns Rev wind turbines and view of wind turbine arrangement

8.3 Type of pylon

The type of pylon that was used is Monopile as can be seen in figure 46. This pylon has a height of 70m, a maximum tower diameter of 4 m and is constructed from stainless steel.

8.4 Type of foundation

The wind turbine pylon was placed at 22.24 m below the level of the sea bed in order to have the appropriate stability against the loads created from wind and wave forces. At the pylon base there is a rubble surface of 0.03 to 0.20 m diameter in order to protect the tower from erosion due to the water stream.

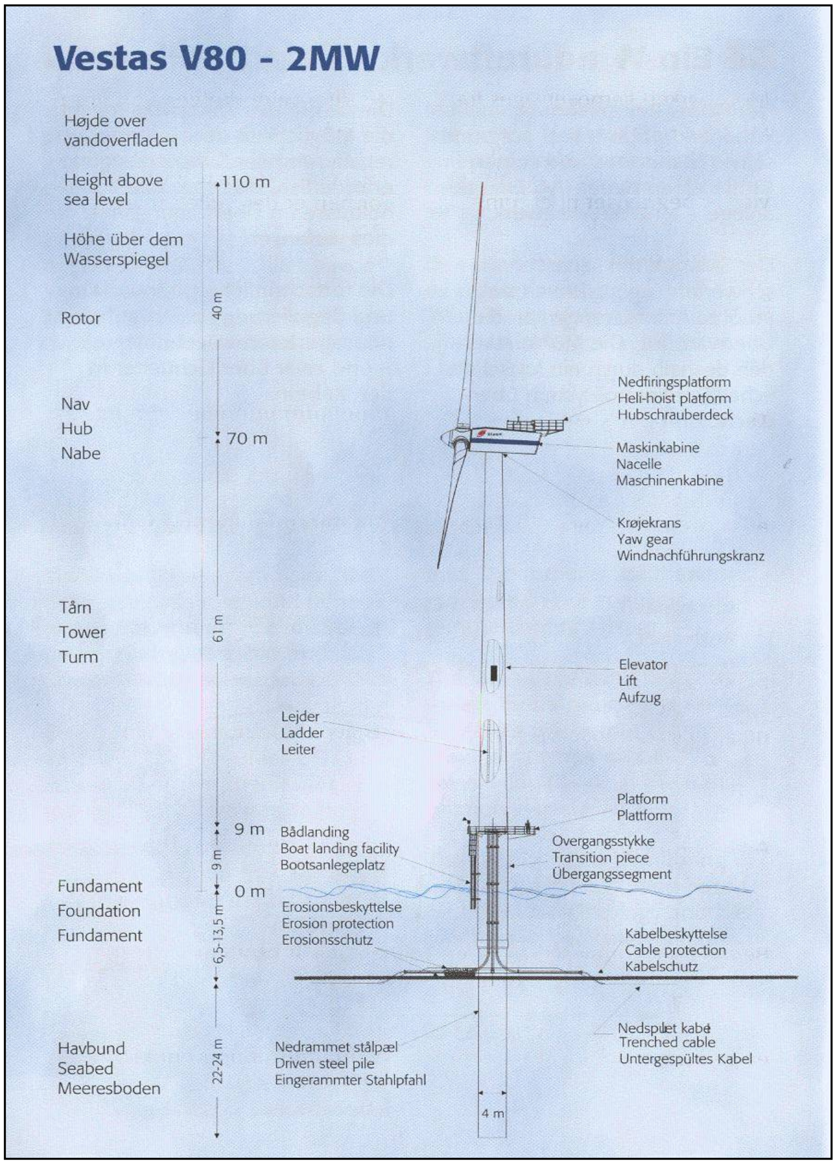


Figure 46: Wind turbine pylon section

8.5 Electrical network connection

The electrical connection of each wind turbine with the platform where the transformer station is placed is done with the use of 34 kV cable connection. At the transformer station the voltage is transformed to 150 kV and through the use of the sea cable it is transported to land. In figure 47 the maximum voltage figures that the electrical connection network can withstand are shown.

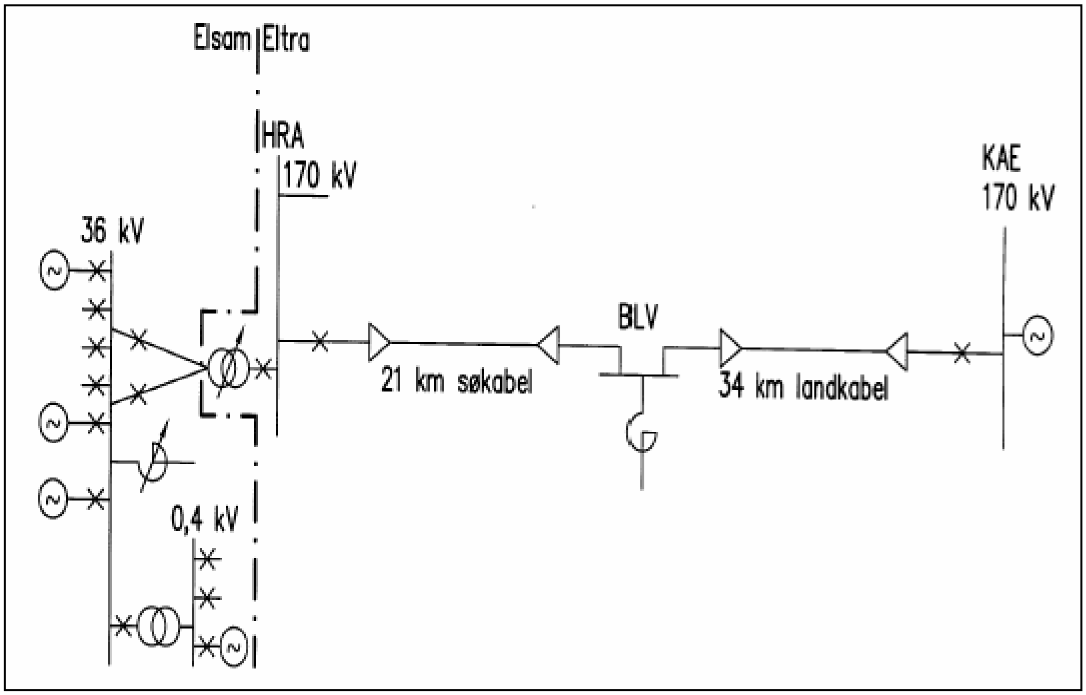
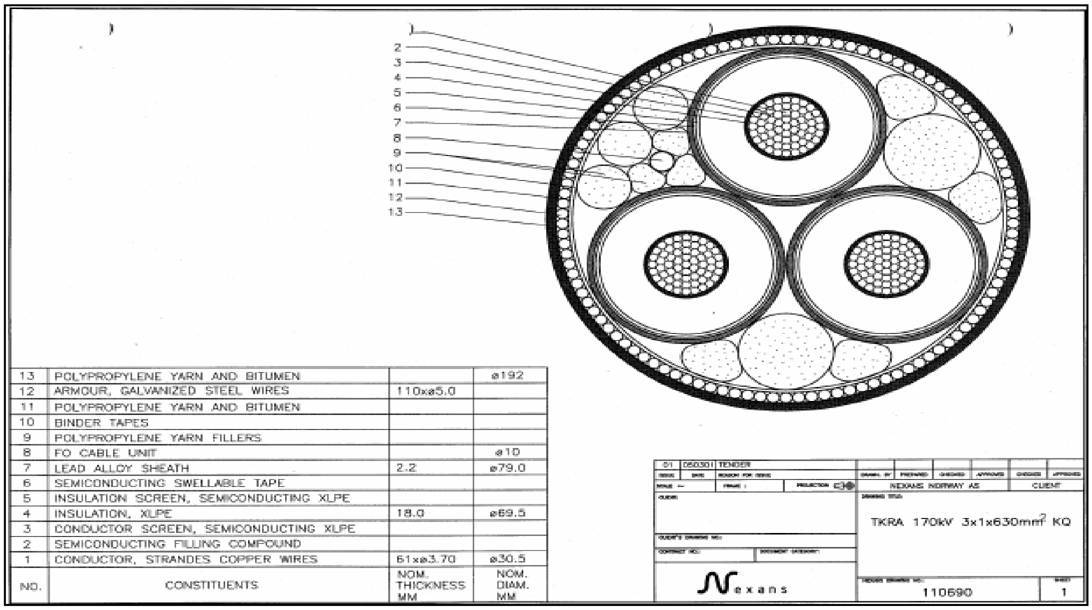


Figure 47: Electrical network connection

The underwater sea cable was constructed in Norway and is the first PEX insulated cable having three conductors. Its diameter is equal to 19.2 cm and it is the largest cable diameter ever made. Apart from the three conductors, it also has optical lenses that make monitoring and operation of the wind park viable from shore. The cable is buried at one meter below the sea bed in order to have better protection.



NO.	CONSTITUENTS	NOM. THICKNESS MM	NOM. DIAM. MM
13	POLYPROPYLENE YARN AND BITUMEN		ø192
12	ARMOUR, GALVANIZED STEEL WIRES	110xø5.0	
11	POLYPROPYLENE YARN AND BITUMEN		
10	BINDER TAPES		
9	POLYPROPYLENE YARN FILLERS		
8	FO CABLE UNIT		ø10
7	LEAD ALLOY SHEATH	2.2	ø79.0
6	SEMICONDUCTING SWELLABLE TAPE		
5	INSULATION SCREEN, SEMICONDUCTING XLPE		
4	INSULATION, XLPE	18.0	ø69.5
3	CONDUCTOR SCREEN, SEMICONDUCTING XLPE		
2	SEMICONDUCTING FILLING COMPOUND		
1	CONDUCTOR, STRANDES COPPER WIRES	61xø3.70	ø30.5

Figure 48: Underwater sea cable section

8.6 Environmental impacts

During the period between February 1999 and May 2000 thorough research was carried out concerning possible environmental impacts that would come from the construction of the offshore wind park. The results showed that there would be no negative consequence on the nearby environment and by spring 2001 authorization for the construction of the offshore wind farm was given. The region close to Horns Rev offshore wind park is monitored continuously in order to detect possible impacts of the wind park on the sea environment and sea organisms.

8.7 Cost figures

The total cost of Horns Rev offshore wind farm was 2 billion DKK, approximately 286 million Euros.

1.7 billion DKK(242 million Euros) were the expenses for the construction and installation of the wind turbines and the remaining 300 millions DKK (44 million Euros)were spent on the construction of the transformer station and the underwater sea cable. Elsam company sells the electricity produced to the electricity market for 0.33 DKK (0.047 Euros), which will remain steady for the first 10 years of operation. It is worth mentioning that Elsam has been approved for an environmental grant equal to 0.1 DKK per KWh (0.014 Euros per KWh).

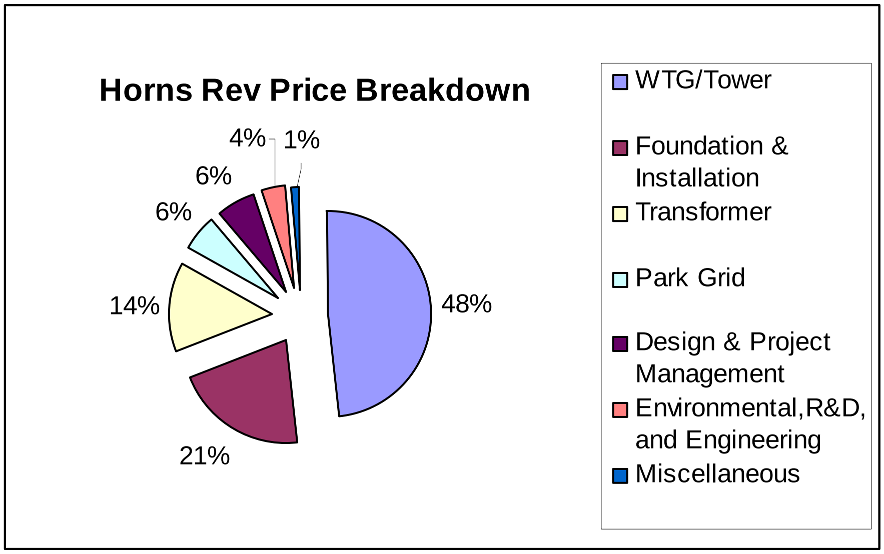


Figure 49: Horns Rev price breakdown

9. Feasibility study

9.1 Fossil fuels depletion problem

Since nowadays, the global economy is powered by fossil fuels, it is vital to know how long world petroleum reserves will last.

At the beginning of the 21st century, the world's reserves of petroleum were estimated to be roughly 1 trillion barrels. Considering the fact that by 2001, worldwide consumption of petroleum totalled 28 billion barrels per year and that there is expected to be an increase of 2.2 % of petroleum consumption per year until the year 2015, we can see that in the era we live, petroleum consumption is greater than petroleum production, so oil resources are approaching to an early end. Apart from the actual yearly petroleum production and consumption, reserves can not be fully appreciated due to political, social and economic factors that can influence oil production and consumption, so actual depletion time can not be calculated.

The main reasons for energy extravagance are the following ones:

i) The continuous increase of energy use per person
ii) Contrast of worldwide energy use between wealthy and non wealthy countries
iii) The increase of the earth's population per year
v) Lack of incentives to save energy

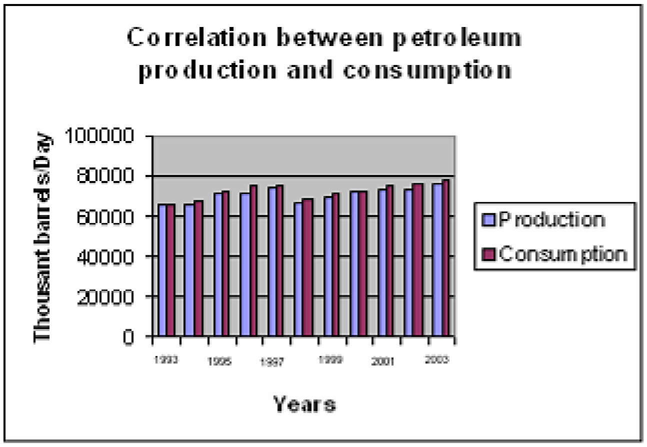


Figure 50: Correlation between worldwide petroleum production and consumption for the year 1993 to 2003[18]

Due to the above reasons, the prospect of reducing the world's dependence on fossil fuel is problematic so there is obviously a need for the use of alternative energy resources.

9.2 Alternative energy resources

Alternative energy resources such as hydroelectric energy, solar, wind, tidal, geothermal energy and so on, are the only ones that can cover our future energy demands.

At the current moment, the electricity demand of the European Union is covered by the sources shown in the figure below.

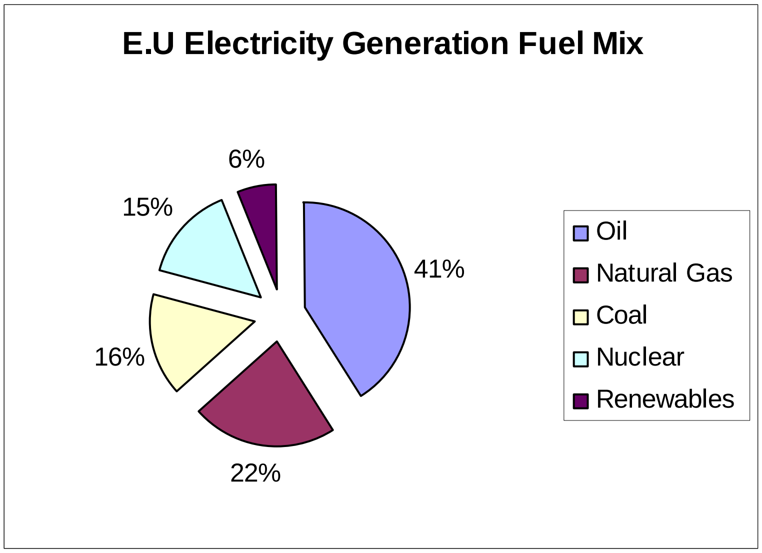


Figure 51: E.U electricity generation fuel mix

It can be observed that electrical energy generated from renewable sources accounts only for 6% of the total fuel mix whilst oil and coal account for 57% of the total fuel mix.

9.3 Energy facts about Greece

Greece covers an area of 131940 km^2 (about the same size as England) and is the southernmost country of the European Union mainland at the moment. According to the year 2001 census it has a population of 10.96 million. It is mainly surrounded by sea and this is the reason for it having more than 2000 islands. Its terrain is primarily mountainous and used mostly as agricultural land.

Figure 52: Map of Greece

In the year 2001 Greece generated 49.8 billion KWh of electricity from thermal sources, hydro-power and renewables.

From the 49.8 KWh of electricity produced, 90% was from coal, 9% from hydro and 1% from solar.

Nowadays, electricity is mainly produced from coal fired sources, hydro and solar. A small percentage of electricity generation comes from a number of small wind farms that have been recently created and connected with the national grid.

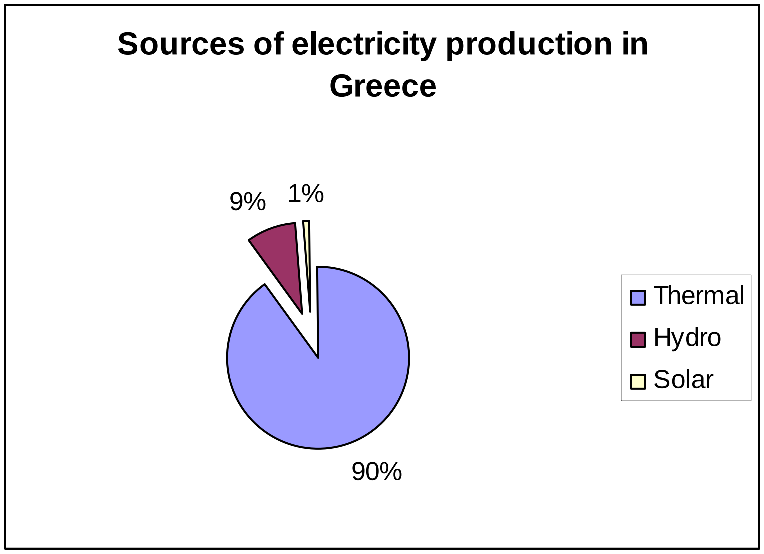


Figure 53: Sources of electricity production in Greece (Year 2001 figures)

During the last decade there has been a growth of approximately 50% on electricity demands so according to the Energy Regulatory Authority (RAE) there is a need for approximately 6000 MW of additional capacity in order to guarantee adequate electricity supply through the year 2015.

According to European Union legislation Greece is required to produce 12% of its electricity from renewable energy sources by the year 2010. In order to achieve this target the Greek government is considering exploring the opportunity of installing wind farms offshore in order to increase its wind power capacity from 270 MW at present to 2000 MW by the year 2010.

Another reason for having in mind the construction of wind farms offshore is the problem that exists on most Greek islands, where diesel generators are used to produce electricity together with huge amounts of CO_2 and many other kinds of emissions. Islands in the west part of Greece such as Corfu and Lefkada are connected to the mainland system by submarine cables, Crete has its own independent grid system, but the rest of the islands that exist in the Aegean Sea are grid independent.

9.4 Case study specifications

For the above reasons feasibility study of placing a 495 MW offshore wind farm in the Aegean Sea in order to balance the increase for electricity demand is going to be carried out.

9.4.1 Site location

Due to the rocky sea bed of the Greek sea, choosing the most appropriate location for building an offshore wind farm is a problem. Apart from that, the maximum recorded water depth of Greek seas is 4900m for the Ionian sea and 3543m for the Aegean sea [20].

There are a number of sites that have sandbanks at water depths close to 35m and a number of available sites close to the Aegean sea islands coastlands with a maximum water depth of 60m.

Since water depths are really great, the only solution to the foundation type of the wind turbines of the offshore wind park would be a floating type which is also suitable for regions suffering from earthquakes.

Since floating type foundations are going to be used for the specific site, it is most appropriate to choose a position for the site that apart from fulfilling the wind potential conditions, is able at an extra cost to provide electricity through the use of underwater cables to a number of islands previously operating with diesel generators.

Due to the high shipping industry and tourism of Greek islands, the location for the offshore wind farm should be at such a site that it does not interfere with the shipping routes and should create the least possible visual impact from the nearby islands.

Another very important aspect that has to be considered is that a number of sites are protected from European Union laws due to their environmental importance such as important fisheries or areas that unique birds or protected animals have as a shelter.

Site location possible problems
Sea bed
Water depths
Shipping
Visual impacts
Earthquakes
E.U protected resorts

Table 23: Site location possible problems

9.4.2 Specific site location

The area shown below was chosen to be the suitable area of installation of the offshore wind park due to the fact that it has little interference with shipping, there is a distance of approximately 40 km from the shore and 15 km from the closest island helping to minimize the visual impact, and has a high wind potential. The specific area of installation is positioned on a sandbank and at an average water depth of 50m.

Figure 54: Specific area for installation of offshore wind park

The location of the site is at the 38th latitude and 24th to 25th longitude, and creates a parallelogram between the islands of Skyros and Chios.

For the specific site we have the following information.

	Average Temperature (° C)												
Lat 38 Lon 25	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Annual Average**
10 Year Average	10.9	10.4	12.1	14.8	18.0	22.0	24.8	25.1	23.0	19.1	15.3	11.9	***17.3***

Table 24: Average Temperature (° C) at Lat 38 and Lon 25 at 10 m above the earth surface

	Average Wind Speed at 50m (m/s)												
Lat 38 Lon 25	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Annual Average**
10 Year Average	7.23	7.61	6.46	5.65	5.05	4.80	6.12	6.07	5.47	5.93	6.50	7.00	***6.15***

Table 25: Average wind speed at 50 m height (m/s)

	Average Wind Speed at 10m (m/s)												
Lat 38 Lon 25	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Annual Average**
10 Year Average	6.18	6.51	5.52	4.83	4.33	4.11	5.23	5.19	4.68	5.07	5.56	5.99	***5.26***

Table 26: Average wind speed at 10 m (m/s)

	Average Atmospheric Pressure (kPa)												
Lat 38 Lon 25	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Annual Average**
10 Year Average	-	-	-	-	-	-	-	-	-	-	-	-	***99.6***

Table 27: Average atmospheric pressure (kPa)

All the above data for the specific site was collected through the use of RETscreen software by following the link for weather database. The above databases were collected from ‘NASA Surface Meteorology and Solar Energy’ tables that are available to download from the RETscreen program. All the data is collected from NASA with the help of a number of sensors placed onshore, offshore and through satellite sensors. The basic assumption that NASA uses for the above wind speed results is that this would be the speed at the specific site if the area of the site looked like an airport without any obstruction. Assuming the above our case study can continue although we will know that our results at the end of our case study will not be accurate, but they are going to be accurate enough in order to see if the above project is feasible or not. In a real life situation the offshore wind speed at the specific location is going to be slightly higher than the one calculated from NASA due to the offshore environment.

An increase of some 20 per cent at some distance from the shore is not uncommon. Given the fact that the energy content of the wind increases with the cube (the third power) of the wind speed, the energy yield may be some 73 per cent higher than on land[21].

9.4.3 Wind turbine

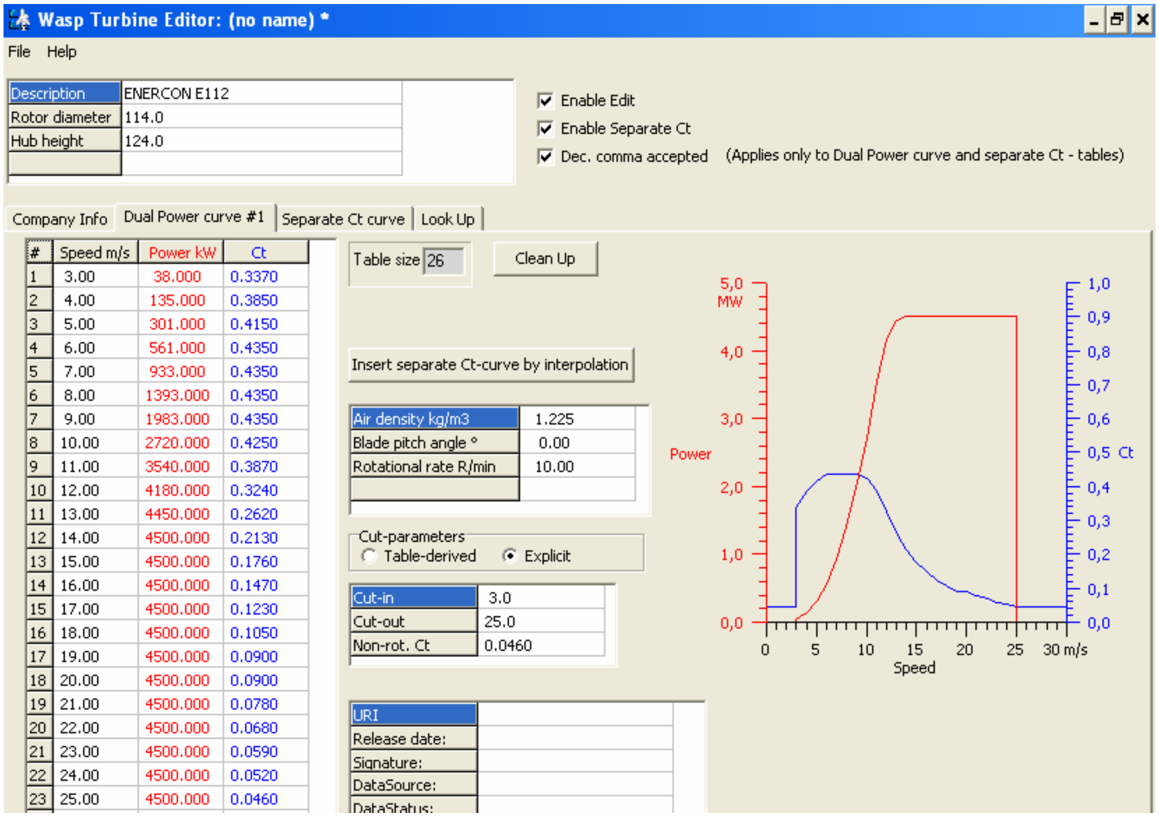
Wind turbines used offshore are usually much larger than the ones used onshore in order to create more electricity to balance their construction costs and have increased corrosion protection. The blade speed of the wind turbines is usually higher than the ones onshore and this is done in order to increase the effectiveness of the wind turbines by 5 to 6%. The higher blade speeds have the disadvantage of creating more noise but since they are located many kilometers offshore, this extra noise, affects only the sea life and not humans. Note however that the impact on sea life is of great importance, humans and fishes have the same importance when designing an offshore wind farm[21].

9.4.3.1 Choice of wind turbine

At the beginning of our project we intended to use a 5 MW wind turbine for our proposed wind farm. Unfortunately this was not possible. Such a wind turbine exists (REPower 5M), but the manufacturer was not able to provide us with information.

Our final choice was to use the Enercon E-112 wind turbine which has a rated output of 4.5 MW and a turbine rotor diameter of 114m and will come into final production by 2009 approximately.

Figure 55: Enercon E-112 wind turbine



Description	ENERCON E112
Rotor diameter	114.0
Hub height	124.0

☑ Enable Edit
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#	Speed m/s	Power kW	Ct
1	3.00	38.000	0.3370
2	4.00	135.000	0.3850
3	5.00	301.000	0.4150
4	6.00	561.000	0.4350
5	7.00	933.000	0.4350
6	8.00	1393.000	0.4350
7	9.00	1983.000	0.4350
8	10.00	2720.000	0.4250
9	11.00	3540.000	0.3870
10	12.00	4180.000	0.3240
11	13.00	4450.000	0.2620
12	14.00	4500.000	0.2130
13	15.00	4500.000	0.1760
14	16.00	4500.000	0.1470
15	17.00	4500.000	0.1230
16	18.00	4500.000	0.1050
17	19.00	4500.000	0.0900
18	20.00	4500.000	0.0900
19	21.00	4500.000	0.0780
20	22.00	4500.000	0.0680
21	23.00	4500.000	0.0590
22	24.00	4500.000	0.0520
23	25.00	4500.000	0.0460

Table size 26

Air density kg/m3	1.225
Blade pitch angle °	0.00
Rotational rate R/min	10.00

Cut-parameters
○ Table-derived ● Explicit

Cut-in	3.0
Cut-out	25.0
Non-rot. Ct	0.0460

URI	
Release date:	
Signature:	
DataSource:	
DataStatus:	

Figure 56: Enercon E-112 wind turbine Power and Ct curve

Further information on Enercon E-112 wind turbine can be found in Appendix 1.

9.4.3.2 Wind turbine grid

110 Enercon E-112 wind turbines are going to be placed at a grid pattern of 11*10, with a distance of 600 m between each turbine. The reason for placing the wind turbines in such a pattern is to give the best utilization of wind while presenting the most harmonic visual impression.

There is a 36 kV cable net that interconnects the wind turbines with the substation that is located in the southwest part of the wind farm.

Another 150kV cable connects the substation through the use of a submarine cable and an onshore cable with the national grid.

The energy produced from the offshore wind farm will be collected from the transformer and then transported through the cables to the onshore grid.

The cables of the wind farm are going to be laid from the cable ship and through the use of water jetting, placed at approximately 1 m into the seabed in order to be protected from fishing tackle and anchors.

The transformer with dimensions of approximately 80*80 m, (Horns Rev transformer has a size of 20*28m)[22] is to be assembled onshore and then transferred by barge to the wind farm and fitted to place.

The distance between Euvoia which will be the area of grid connection and the offshore wind farm is approximately 40 km. In case we choose to connect a number of small islands with the offshore wind farm, a great deal of cabling will be needed in addition to electricity sub-stations on each island, that will increase the cost dramatically.

An area of approximately 2 km has to be established around the wind farm as a protection zone where fishing, shipping and anchoring is going to be prohibited.

9.4.3.3 Wind turbine direction

Since almost 100% of the wind energy comes from the north-west direction, the wind turbines will be placed with their hub fixed in a north-west direction.

9.5 Wind turbine foundations

For the wind turbine foundations tension leg platforms are going to be used, like the one previously shown in figure 25. Their design is going to more expensive than ordinary types of foundations used such as monopile, but due to the fact that less material is used for this type of design (less steel or less concrete) in the future such kind of foundations will be cost effective. The wind turbine pylon is going to extend at 10 m below the sea surface in order to minimize the wave loads and maximize the platform stability. Icing problems are not going to be present, thus reducing the foundation costs.

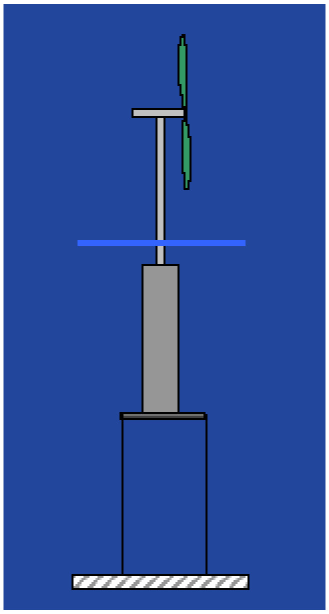


Figure 57: Proposed wind turbine foundation method

9.6 Environmental impacts

The main impact is going to be the noise created from the installation of the wind turbines together with the pollution created in the sea from cranes and barges during the installation of the wind turbine.

9.6.1 Manufacturing impacts

Manufacturing impacts will be mainly considered on land. The main manufacturing impact will be the waste material created during the manufacturing stage of the wind turbines and the gaseous emissions produced from the transportation stage of the wind turbine components to the port.

9.6.2 Wind turbine installation impacts

Since tension leg platforms are going to be used for each wind turbine, no sea bed preparation is needed. Divers are going to stabilize the platform anchors and connect the cabling of each wind turbine with the transformer. During the installation period, sea and air pollution is going to be created by the cranes and barges used for installation. Underwater noise will lead to the creation of a poor fishery area due to temporary fish migration.

Once the turbines are operational, the local fishery will return to its original condition or even increase, due to the fact that local fauna and flora will increase the fish food in the specific area. The physical presence of the wind turbines themselves is going to create a visual intrusion to the human eye but due to the distance from the shore and due to their colour which will be wither ‘Navy Gray’ or completely white, the visual intrusion is going to be negligible.

9.6.3 Wind turbine decommissioning impacts

Due to the foundation design, at the end of the life cycle of the wind turbines and the foundations, there will be no environmental impacts. The wind turbines can be easily removed from the foundation with the help of a crane and the foundations can be removed by either removing the anchor from the seabed or by simply cutting the cable that keeps them in a steady position.

9.6.4 Ship collision risks

Ship collision with one or more of the wind turbines can occur due to a number of factors such as human error, mechanical failure or steering failure.

Since a protection zone of 2 km has been established around the wind park, probabilities of having a ship collide with one or more of the wind turbines are very low. Possible protective measures such as boat fender piles or an artificial protective reef can be used in order to reduce the impacts in case of a ship collision.

In the case of a ship collision the tremendous damage that can be caused can be found in chapter 5.1.5.9 and figure 37.

9.7 Assumptions

The wind turbines will have to be provided with lightning protection in order to reduce the risks of being struck by lightning.

Wind turbines should be fitted with lights in order to reduce the risk of collision with ships and aeroplanes.

During the maintenance period of each turbine or in case of a wind turbine malfunction, the personnel might have to spend the night at the wind turbine site. For the above reason each wind turbine should be equipped with food, toilets and sleeping bags in case the weather conditions or the damage of the wind turbine does not allow them to spend the night onshore.

As extra equipment, the wind turbines positioned in each corner of the site should be equipped with a special platform on top of the nacelle, to allow access to the wind turbines if the weather conditions make access by boat impossible. Apart from the weather condition factor, the helipad can be used for personnel transportation because it saves travel time.

Therefore an Offshore Access System (OAS) should be used for the transportation of personnel and small components.

9.8 Cost components

The cost components of an offshore wind farm can be decomposed into three major contributions areas.

The first one which is also the largest one is the investment cost at the beginning of wind farm’s life since energy production starts after the end of the construction period.

The second contribution is the operating and maintenance costs that should be considered during the whole life cycle of the offshore wind farm and finally the third factor is the decommissioning costs that arise immediately after the last year of energy production of the offshore wind farm.

The investment cost that occurs at the beginning of the wind farms life can be further decomposed into the design and acquisition stage.

At this stage, engineers are the ones that are responsible for designing the offshore wind farm from scratch and purchasing the necessary equipment for the construction of the wind farm. As necessary equipment we should consider the wind turbine together with the support structure, the electrical infrastructure needed for the operation of the wind turbines, the cost of transportation and installation of the wind turbines and the project management needed in order that every part of the construction of the offshore wind park be carried out exactly as scheduled and at the proper time.

During the operation and maintenance phase, the cost of maintenance of the wind park, the cost of repairing the wind turbines and other recurring costs such as insurance and administrative costs are considered.

At the final stage of the life cycle of the wind park, the decommissioning stage, all the decommissioning activities needed in order to bring the area of installation of the wind park in its original form without leaving any possible sources of environmental impact are considered, together with the revenues from the recycling of materials and components of the wind farm.(revenues from recovering are not considered for this project although a graphical presentation of recovering costs will be described later on).

9.8.1 Further economic details considering the case study of a 495 MW deep offshore wind park

Due to the fact that it will be the first wind park located in such water depths (from 35m to 60m), and the fact that companies work in privacy to design multi megawatt turbines using floating foundations that can be used in great water depths, collecting information from the wind energy companies was almost impossible.

For this reason, the costs that were used for the design of the 495 MW wind park were either based on literature and web resources or were calculated according to recent figures for offshore wind park costs by approximation of current and future cost figures.

Initial costs	**Component**	**Cost (Euros)**
Feasibility study	Meteorological mast	370,000
	Site survey	370,000
	Meteorological mast foundations	50,000
	Measuring campaign	100,000
Development	Planning, EIA, reporting,etc	2,934,700
Foundations	Engineering cost of foundations, tension legs and seabed structural base	520,323,000
Wind turbines	Design and Installation	792,000,000
	Transportation	429,000
	Ladders, Marinisation, lighting	242,000
Grid connection	45 km of 150kV sea cable	11,700,000
	50 km of 30kV cable	5,000,000
	Cable laying and burial	6,600,000
	Wind turbine connectors	4,070,000
	Vessel rental	11,000,000
	H.V station	25,000,000
	Grid onshore work	30,000,000
Operation and maintenance costs	Preventive maintenance costs	8,800,000
	Contingencies	880,000
Total design costs		**1,416,934,000 Euros**
Total cost / kW		2,862.5 Euros/kW

Table 28: Costs of each component

9.8.2 Specific costs

The parameter that has to be first examined for the creation of an offshore wind park is the wind potential of the specific site as previously mentioned. For that reason, there is a need for a site survey in order to establish how feasible the project is going to be.

A site survey includes the cost of erecting a meteorological mast at the proposed sites in order to obtain the most accurate data for each proposed site. The cost of the meteorological mast includes the cost of the mast, of the instrumentation needed for recording the wind data characteristics and the foundation needed for the meteorological mast. A measuring campaign has to be done in order to collect accurate information from the best proposed site and then the properties of the specific site such as geophysical properties and wave heights have to be considered in order to choose the exact wind turbine location.

The next step is the development stage where the actual view of the proposed site is clear in the engineers mind, so project management takes place including administration costs, planning, projects controls, monitoring and reporting. An environmental impact assessment has to be done in order to inform the authorities about any possible impacts that the construction of the specific site might have in order to receive planning permission from the authorities.

The next cost figure is the foundation costs. The foundation costs include the cost of marinisation of the structure in addition to the cost of the platform, tension leg and the seabed structural base needed in order to stabilise the whole design.

Wind turbine costs include the cost of rotor, the drive train, nacelle housing and bedplate, control and safety system and the cost of the electrical generation system.

Grid connection includes the cost of the transformer and the power transmission system through the use of cables both onshore and offshore.

Other possible cost factors are the maintenance costs depending on the period of maintenance (either preventive or corrective maintenance) and costs due to taxation and any other contingencies that might occur either during the construction or the operation phase of the wind farm.

In chapter 9.10, the analysis of the costs that were used on the RETscreen model and the actual cost per kW excluding taxes or credits of the project can be seen.

9.9 RETscreen software

RETscreen program is a tool developed from the ‘Ministry of Natural Resources of Canada’ in 1997, which has since then been a useful tool, in order to calculate the wind potential, actual wind energy production of a specific site, the costs of the construction phase and annual and periodic costs and so on.

Due to the parameters used for the design of each project, RETscreen software allows the user to calculate annual savings from the use of renewable energy sources instead of fossil fuels previously used and emission reductions from the operation of the wind farm. At the financial summary stage, a cumulative cash flow graph is shown in order to determine the repayment period.

9.10 RETscreen results

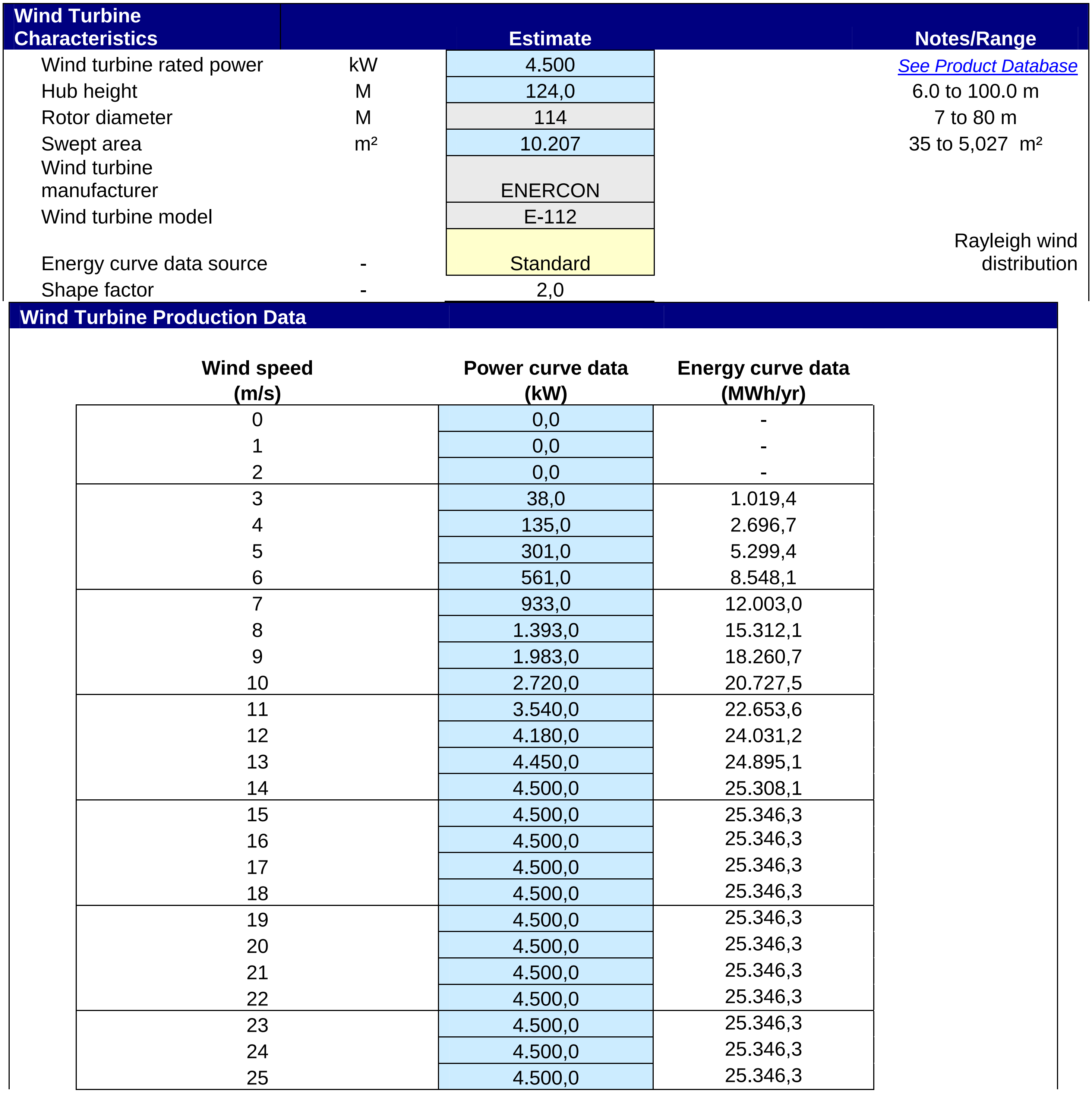
Annual Energy Production		Estimate Per Turbine	Estimate Total	Notes/Range
Wind plant capacity	kW	4.500	495.000	
	MW	4,500	495,000	
Unadjusted energy production	MWh	15.077	1.658.519	
Pressure adjustment coefficient	-	0,98	0,98	0.59 to 1.02
Temperature adjustment coefficient	-	0,99	0,99	0.98 to 1.15
Gross energy production	MWh	14.628	1.609.095	

Site Conditions		Estimate	Notes/Range
Project name		**Wind Park**	
Project location		**Aegean Sea,Greece**	
Wind data source		Wind speed	
Nearest location for weather data		NASA satellite	
Annual average wind speed	m/s	5,3	
Height of wind measurement	M	10,0	3.0 to 100.0 m
Wind shear exponent	-	0,16	0.10 to 0.40
Wind speed at 10 m	m/s	5,3	
Average atmospheric pressure	kPa	99,6	60.0 to 103.0 kPa
Annual average temperature	°C	17	-20 to 30 °C

System Characteristics		Estimate	Notes/Range
Grid type	-	Central-grid	
Wind turbine rated power	kW	4.500	
Number of turbines	-	110	
Wind plant capacity	kW	495.000	
Hub height	M	124,0	6.0 to 100.0 m
Wind speed at hub height	m/s	7,9	
Wind power density at hub height	W/m²	584	
Array losses	%	15%	0% to 20%
Airfoil soiling and/or icing losses	%	1%	1% to 10%
Other downtime losses	%	2%	2% to 7%
Miscellaneous losses	%	6%	2% to 6%

Losses coefficient	-	0,78	0,78	0.75 to 1.00
Specific yield	kWh/m²	1.111	1.111	150 to 1,500 kWh/m²
Wind plant capacity factor	%	29%	29%	20% to 40%
Renewable energy delivered	MWh	11.340	**1.247.354**	
	GJ	40.823	4.490.475	

Table 29: Energy model



Wind Turbine Characteristics		Estimate	Notes/Range
Wind turbine rated power	kW	4.500	*See Product Database*
Hub height	M	124,0	6.0 to 100.0 m
Rotor diameter	M	114	7 to 80 m
Swept area	m²	10.207	35 to 5,027 m²
Wind turbine manufacturer		ENERCON	
Wind turbine model		E-112	
Energy curve data source	-	Standard	Rayleigh wind distribution
Shape factor	-	2,0	

Wind Turbine Production Data

Wind speed (m/s)	Power curve data (kW)	Energy curve data (MWh/yr)
0	0,0	-
1	0,0	-
2	0,0	-
3	38,0	1.019,4
4	135,0	2.696,7
5	301,0	5.299,4
6	561,0	8.548,1
7	933,0	12.003,0
8	1.393,0	15.312,1
9	1.983,0	18.260,7
10	2.720,0	20.727,5
11	3.540,0	22.653,6
12	4.180,0	24.031,2
13	4.450,0	24.895,1
14	4.500,0	25.308,1
15	4.500,0	25.346,3
16	4.500,0	25.346,3
17	4.500,0	25.346,3
18	4.500,0	25.346,3
19	4.500,0	25.346,3
20	4.500,0	25.346,3
21	4.500,0	25.346,3
22	4.500,0	25.346,3
23	4.500,0	25.346,3
24	4.500,0	25.346,3
25	4.500,0	25.346,3

Table 30: Equipment Data

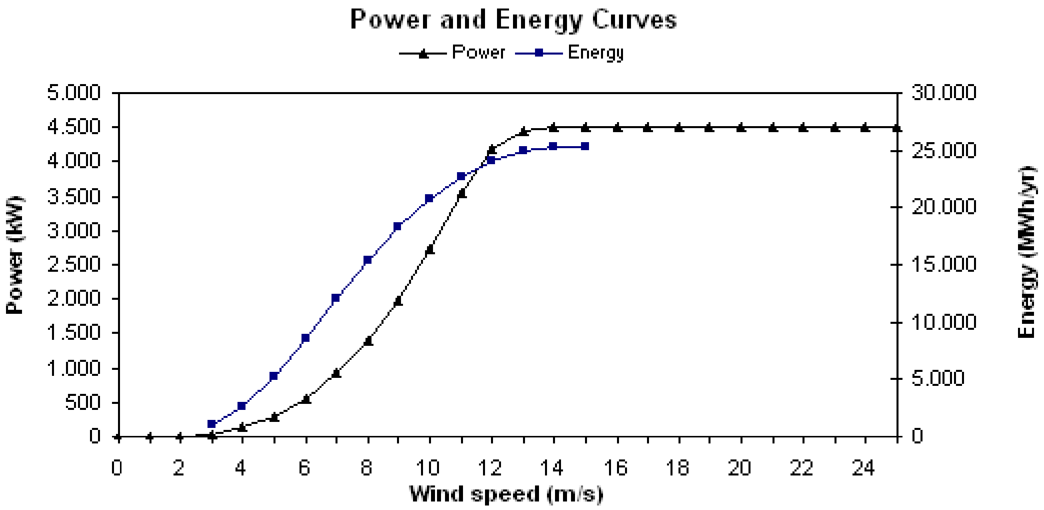


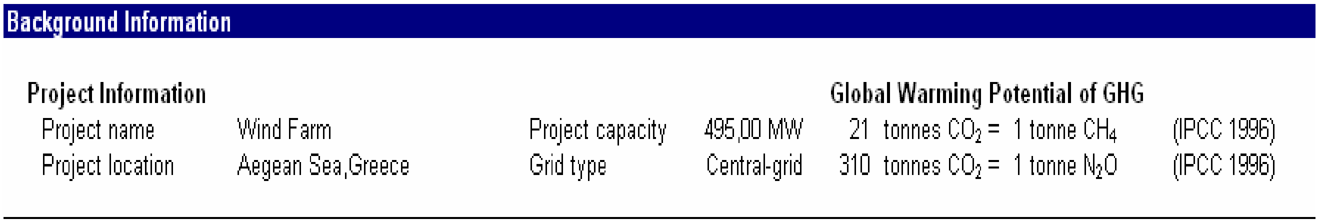
Table 31: Power and energy curves

Initial Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs
Feasibility Study					
Feasibility study	Cost	1	€ 890.000	€ 890.000	
Sub-total:				**€ 890.000**	0,1%
Development					
Development	Cost	1	€ 2.934.700	€ 2.934.700	
Sub-total:				**€ 2.934.700**	0,2%
Engineering					
Engineering	Cost	110	€ 4.730.200	€ 520.322.000	
Sub-total:				**€ 520.322.000**	33,8%
Energy Equipment					
Wind turbine(s)	kW	495.000	€ 1.600	€ 792.000.000	
Spare parts	%	0,0%	€ 792.000.000	€ -	
Transportation	turbine	110	€ 3.900	€ 429.000	
Structural steelwork	Cost	110	€ 2.200	€ 242.000	
Sub-total:				**€ 792.671.000**	51,5%
Balance of Plant					
Grid connection	Cost	1	€ 93.000.000	€ 93.000.000	
Sub-total:				**€ 93.000.000**	6,0%
Miscellaneous					
Contingencies	%	5%	€1.409.817.700	€ 70.490.885	
Interest during construction	8,0%	12 month(s)	€1.480.308.585	€ 59.212.343	
Sub-total:				**€ 129.703.228**	8,4%
Initial Costs – Total				**€ 1.539.520.928**	100,0%

Annual Costs (Credits)		Unit	Quantity	Unit Cost	Amount	Relative Costs
O&M						
	O&M	Cost	110	€ 80.000	€ 8.800.000	
	Contingencies	%	10%	€ 8.800.000	€ 880.000	
Annual Costs – Total					**€ 9.680.000**	100,0%

Periodic Costs (Credits)			Period	Unit Cost	Amount
	Drive train	Cost	10 yr	€ 2.000.000	**€ 2.000.000**
	Blades	Cost	15 yr	€ 2.000.000	**€ 2.000.000**
		Credit			**€ -**
	End of project life	Credit	-	€ 8.804.108	**€ (8.804.108)**

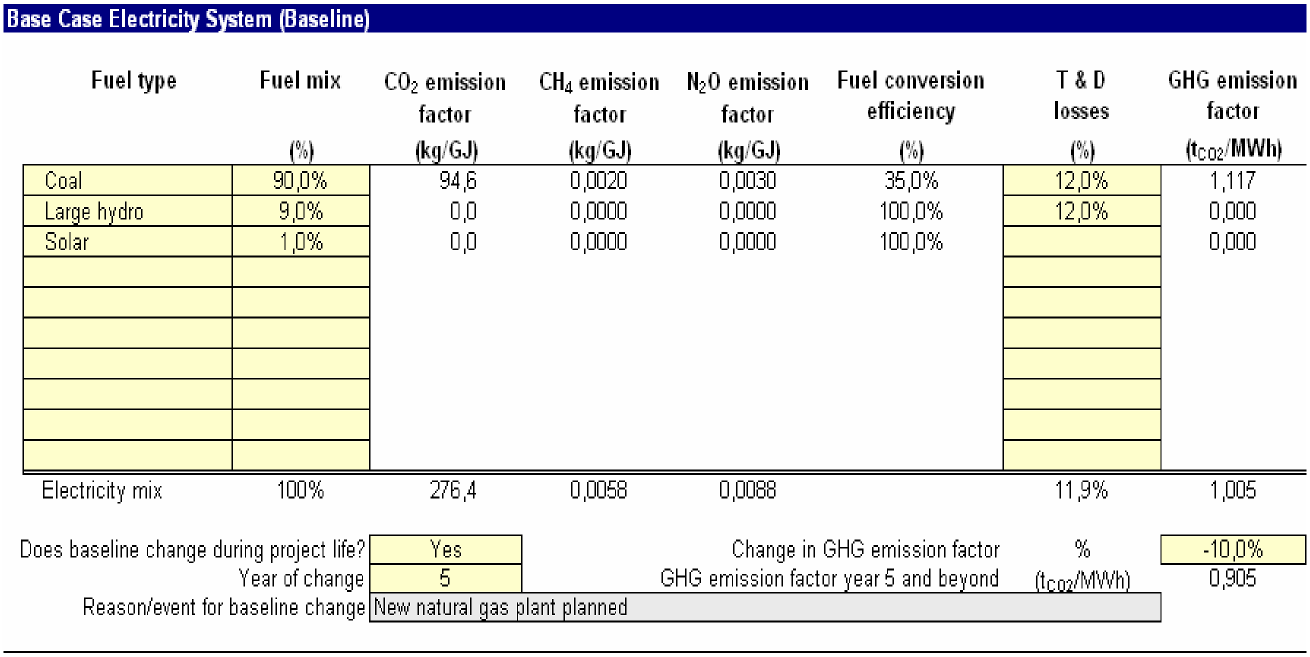
Table 32: Cost analysis



Background Information

Project Information				Global Warming Potential of GHG	
Project name	Wind Farm	Project capacity	495,00 MW	21 tonnes CO_2 = 1 tonne CH_4	(IPCC 1996)
Project location	Aegean Sea,Greece	Grid type	Central-grid	310 tonnes CO_2 = 1 tonne N_2O	(IPCC 1996)

Table 33: Project background information

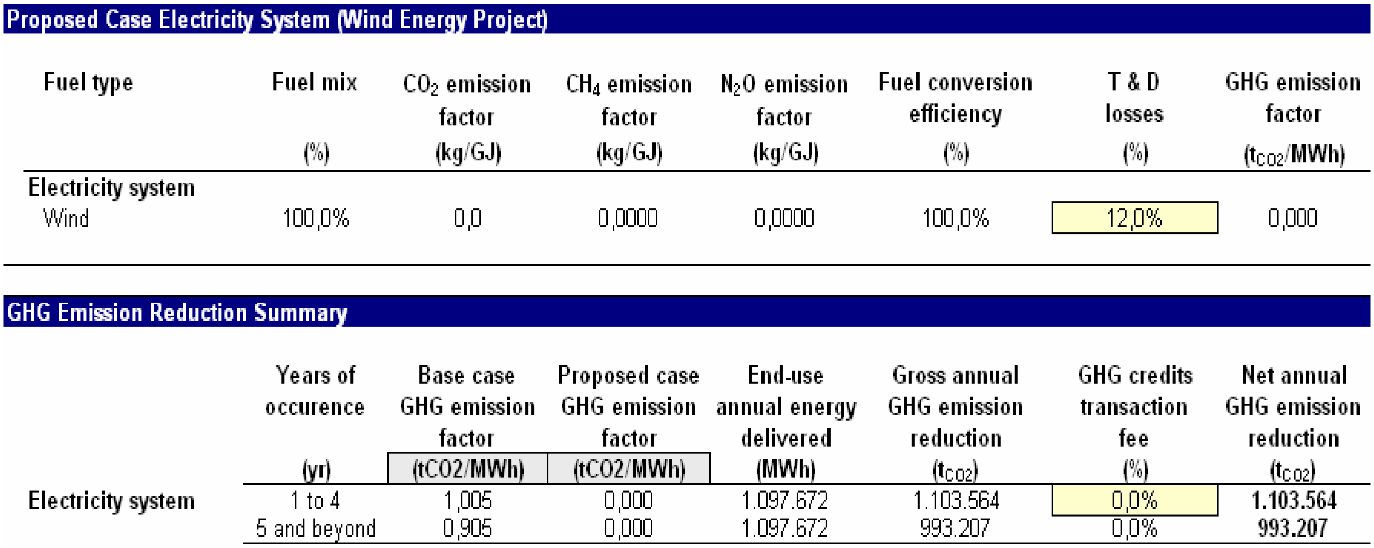


Base Case Electricity System (Baseline)

Fuel type	Fuel mix (%)	CO_2 emission factor (kg/GJ)	CH_4 emission factor (kg/GJ)	N_2O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (t_{CO2}/MWh)
Coal	90,0%	94,6	0,0020	0,0030	35,0%	12,0%	1,117
Large hydro	9,0%	0,0	0,0000	0,0000	100,0%	12,0%	0,000
Solar	1,0%	0,0	0,0000	0,0000	100,0%		0,000
Electricity mix	100%	276,4	0,0058	0,0088		11,9%	1,005

Does baseline change during project life?	Yes	Change in GHG emission factor	%	-10,0%
Year of change	5	GHG emission factor year 5 and beyond	(t_{CO2}/MWh)	0,905
Reason/event for baseline change	New natural gas plant planned			

Table 34: Distribution of current electricity system of Greece



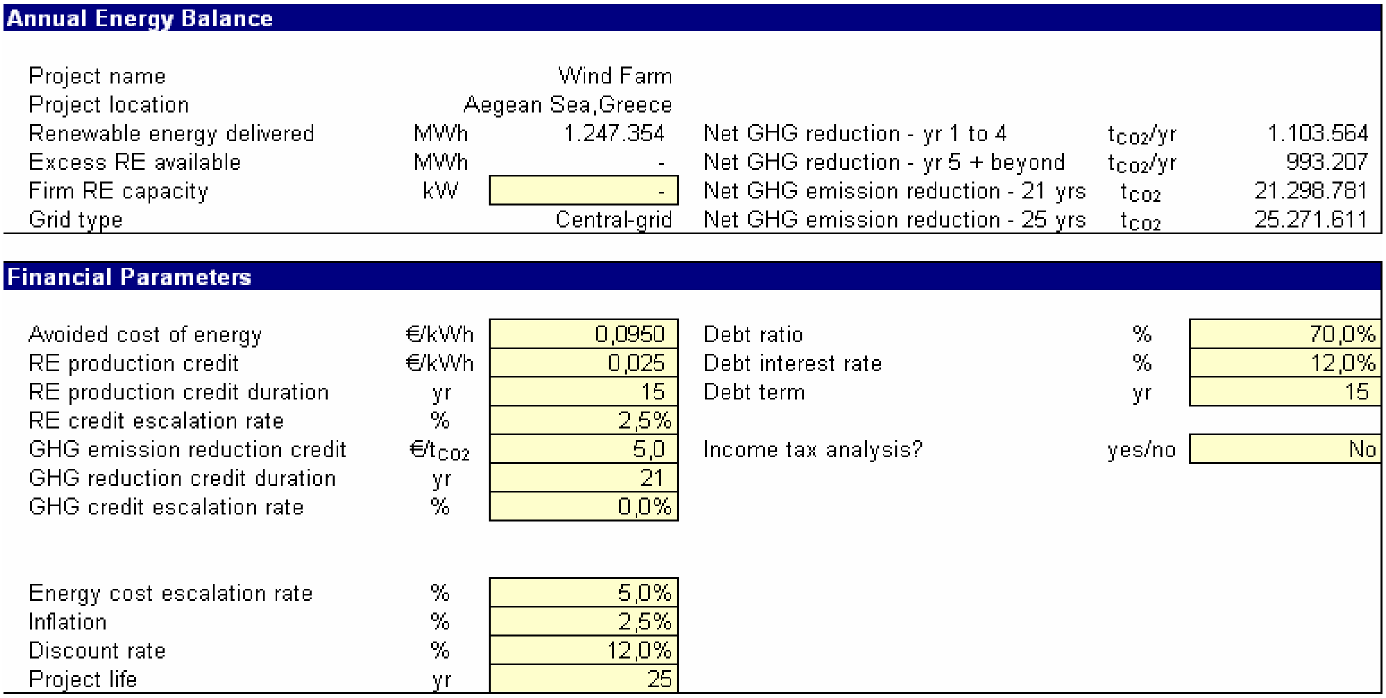
Proposed Case Electricity System (Wind Energy Project)

Fuel type	Fuel mix (%)	CO_2 emission factor (kg/GJ)	CH_4 emission factor (kg/GJ)	N_2O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (t_{CO2}/MWh)
Electricity system							
Wind	100,0%	0,0	0,0000	0,0000	100,0%	12,0%	0,000

GHG Emission Reduction Summary

	Years of occurence (yr)	Base case GHG emission factor (tCO2/MWh)	Proposed case GHG emission factor (tCO2/MWh)	End-use annual energy delivered (MWh)	Gross annual GHG emission reduction (t_{CO2})	GHG credits transaction fee (%)	Net annual GHG emission reduction (t_{CO2})
Electricity system	1 to 4	1,005	0,000	1.097.672	1.103.564	0,0%	**1.103.564**
	5 and beyond	0,905	0,000	1.097.672	993.207	0,0%	**993.207**

Table 35: Green house gases emission reduction summary



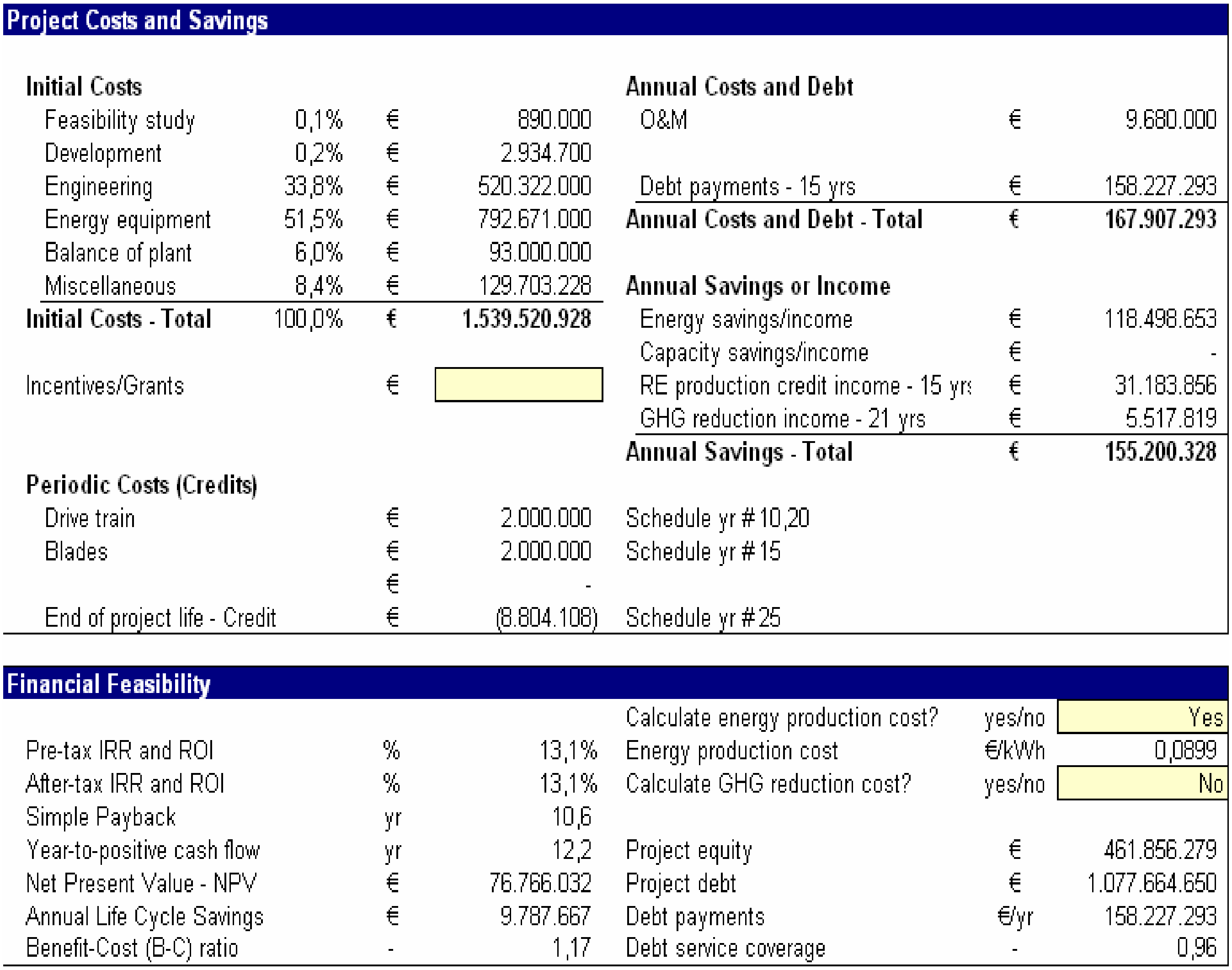
Annual Energy Balance

Project name		Wind Farm			
Project location		Aegean Sea,Greece			
Renewable energy delivered	MWh	1.247.354	Net GHG reduction - yr 1 to 4	t_{CO2}/yr	1.103.564
Excess RE available	MWh	-	Net GHG reduction - yr 5 + beyond	t_{CO2}/yr	993.207
Firm RE capacity	kW	-	Net GHG emission reduction - 21 yrs	t_{CO2}	21.298.781
Grid type		Central-grid	Net GHG emission reduction - 25 yrs	t_{CO2}	25.271.611

Financial Parameters

Avoided cost of energy	€/kWh	0,0950	Debt ratio	%	70,0%
RE production credit	€/kWh	0,025	Debt interest rate	%	12,0%
RE production credit duration	yr	15	Debt term	yr	15
RE credit escalation rate	%	2,5%			
GHG emission reduction credit	€/t_{CO2}	5,0	Income tax analysis?	yes/no	No
GHG reduction credit duration	yr	21			
GHG credit escalation rate	%	0,0%			
Energy cost escalation rate	%	5,0%			
Inflation	%	2,5%			
Discount rate	%	12,0%			
Project life	yr	25			

Table 36: Annual energy balance and financial parameters



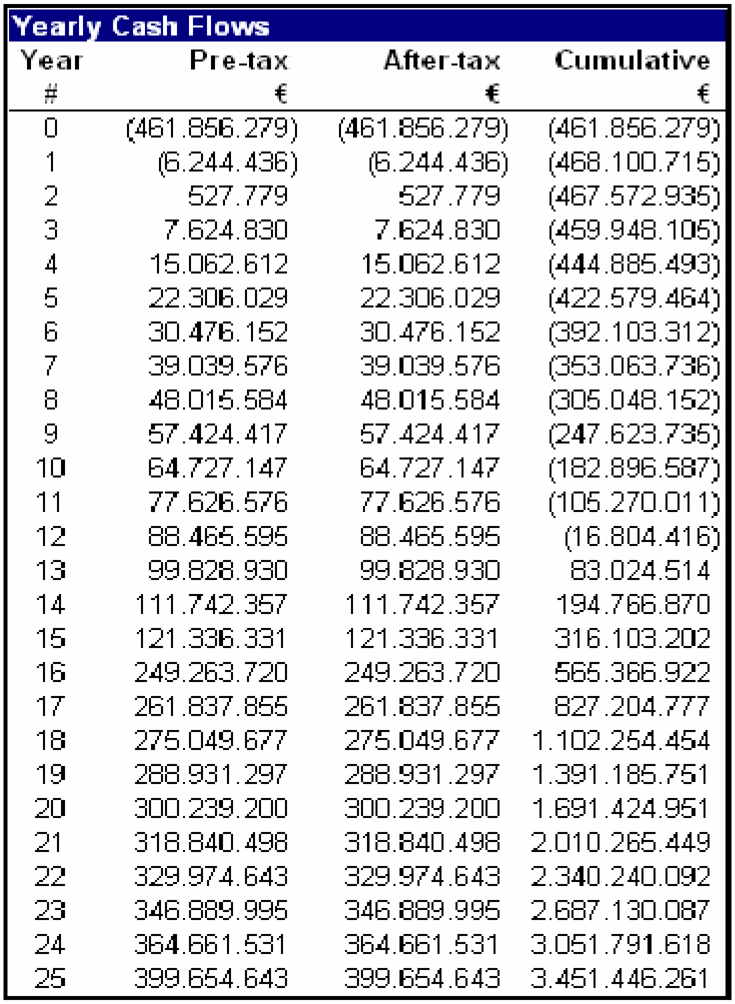
Project Costs and Savings

Initial Costs				**Annual Costs and Debt**		
Feasibility study	0,1%	€	890.000	O&M	€	9.680.000
Development	0,2%	€	2.934.700			
Engineering	33,8%	€	520.322.000	Debt payments - 15 yrs	€	158.227.293
Energy equipment	51,5%	€	792.671.000	**Annual Costs and Debt - Total**	€	**167.907.293**
Balance of plant	6,0%	€	93.000.000			
Miscellaneous	8,4%	€	129.703.228	**Annual Savings or Income**		
Initial Costs - Total	100,0%	€	**1.539.520.928**	Energy savings/income	€	118.498.653
				Capacity savings/income	€	-
Incentives/Grants		€		RE production credit income - 15 yr	€	31.183.856
				GHG reduction income - 21 yrs	€	5.517.819
				Annual Savings - Total	€	**155.200.328**
Periodic Costs (Credits)						
Drive train		€	2.000.000	Schedule yr # 10,20		
Blades		€	2.000.000	Schedule yr # 15		
		€	-			
End of project life - Credit		€	(8.804.108)	Schedule yr # 25		

Financial Feasibility

			Calculate energy production cost?	yes/no	Yes
Pre-tax IRR and ROI	%	13,1%	Energy production cost	€/kWh	0,0899
After-tax IRR and ROI	%	13,1%	Calculate GHG reduction cost?	yes/no	No
Simple Payback	yr	10,6			
Year-to-positive cash flow	yr	12,2	Project equity	€	461.856.279
Net Present Value - NPV	€	76.766.032	Project debt	€	1.077.664.650
Annual Life Cycle Savings	€	9.787.667	Debt payments	€/yr	158.227.293
Benefit-Cost (B-C) ratio	-	1,17	Debt service coverage	-	0,96

Table 37: Project costs and energy production costs



Yearly Cash Flows

Year \#	Pre-tax €	After-tax €	Cumulative €
0	(461.856.279)	(461.856.279)	(461.856.279)
1	(6.244.436)	(6.244.436)	(468.100.715)
2	527.779	527.779	(467.572.935)
3	7.624.830	7.624.830	(459.948.105)
4	15.062.612	15.062.612	(444.885.493)
5	22.306.029	22.306.029	(422.579.464)
6	30.476.152	30.476.152	(392.103.312)
7	39.039.576	39.039.576	(353.063.736)
8	48.015.584	48.015.584	(305.048.152)
9	57.424.417	57.424.417	(247.623.735)
10	64.727.147	64.727.147	(182.896.587)
11	77.626.576	77.626.576	(105.270.011)
12	88.465.595	88.465.595	(16.804.416)
13	99.828.930	99.828.930	83.024.514
14	111.742.357	111.742.357	194.766.870
15	121.336.331	121.336.331	316.103.202
16	249.263.720	249.263.720	565.366.922
17	261.837.855	261.837.855	827.204.777
18	275.049.677	275.049.677	1.102.254.454
19	288.931.297	288.931.297	1.391.185.751
20	300.239.200	300.239.200	1.691.424.951
21	318.840.498	318.840.498	2.010.265.449
22	329.974.643	329.974.643	2.340.240.092
23	346.889.995	346.889.995	2.687.130.087
24	364.661.531	364.661.531	3.051.791.618
25	399.654.643	399.654.643	3.451.446.261

Table 38: Yearly cash flows

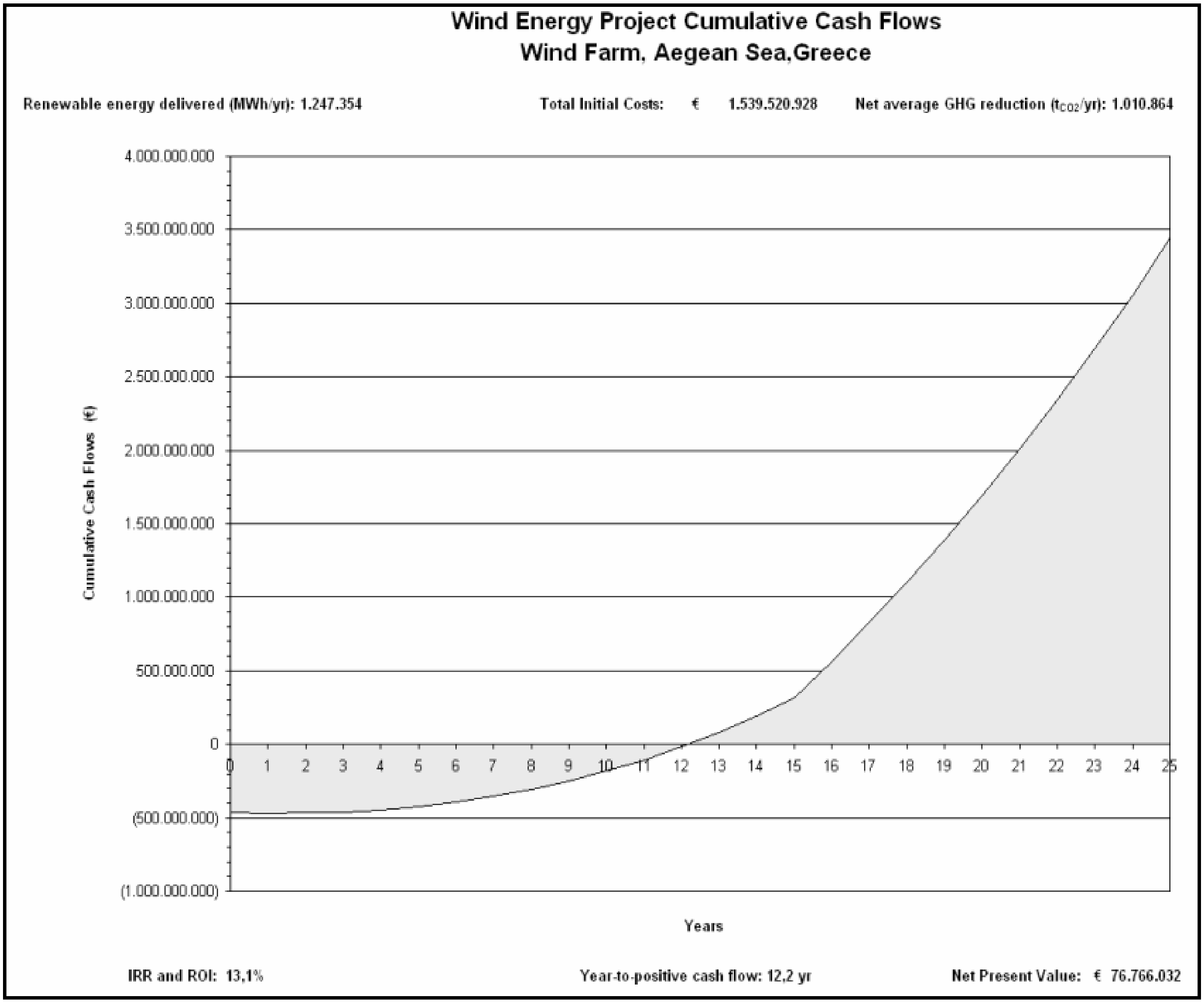


Table 39: Graphical output of yearly cash flows

9.11 Assumptions made and reference values used for the completion of the 500 MW wind farm project

9.11.1 Foundation costs

Since such kinds of foundation and at such a water depth have never been used in the past, calculating the actual cost of the foundations was a very difficult task.

After studying a number of different bibliography resources, it was decided to use the price of 4,290,000 Euros for each turbine foundation. The reason was that according to a paper called ‘Cost and Potential of Offshore Wind Energy on the Dutch Part of the North Sea’ the cost of either a monopile or tripod foundation for a 2.5 MW wind turbine situated at a water depth of 20 m is approximately 3 million Euros.

According to a paper published from Greenpeace called ‘North Sea Offshore Wind-A Powerhouse for Europe’, the cost increase of the foundations for a 2.5 MW wind turbine with an actual cost of 867 Euros/kW increases by approximately 43% if placed at a water depth of 50m.

So in our case we used the above figure of 3 million Euros multiplied by the extra foundation costs for placing the foundation at 50 m water depth which is 43% increase for each wind turbine foundation and we reached the conclusion of a cost of 429,000,000 euros.

If we multiply this number by the number of the wind turbines (110 wind turbines used) the value of 471,900,000 Euros is reached.

For the tension leg foundations at 50 m according to ‘Cost and Potential of Offshore Wind Energy on the Dutch Part of North Sea’ again, there is a need for 200 tonnes of steel per each wind turbine for the sea bed foundation.

The cost of each tonne of steel according to the paper ‘OFFSHORE WIND: An Economy of Scale, Engineering Resource and Load Factors’ is approximately 1500 British pounds, approximately 2200 Euros per tonne.

200 tonnes are needed for 110 foundations, which is 22000 tonnes of steel multiplied by 2200 Euros per tonne, or 48,400,000 Euros.

Using the above assumptions, the price of the foundations that was used for the RETscreen software program was 520,322,000 Euros in total.

9.11.2 Wind Turbines Cost

Estimating the cost of each wind turbine was another difficult task.

The actual price we used for our calculations was 1600 Euro/kW.

For Horns Rev offshore wind park, the cost of the wind turbines and their foundations that were placed at a water depth of between 5 and 11 m was considered to be 1670 Euros/kW. This was the final installation price excluding the cost of grid connection. For the other Danish offshore wind farms the price per kW of the wind turbines used is approximately 1411 Euros/kW according to ‘Seawind Feasibility study guidelines’.

According to Paul Morthost of Riso National Laboratory, for a 1000 MW offshore wind park at water depths between 20 and 50m, using a 3 MW wind turbine which is the maximum that current technology can offer, the actual cost per kW of the wind turbines would be 624 Euros/kW for the wind turbines and 36 Euro per kW for the installation costs.

Considering the above prices, we have chosen to use the price of 1600 Euros/kW, although it is the worst scenario price, due to the fact that a large amount of money will have to be spent on optimizing the technology used for the 4.5 MW wind turbine in order to be able to withstand the offshore conditions. Apart from that, the installation of a helipad at the wind turbines hub in each corner of the wind farm, the supply of lightning protection, the painting of the wind turbines, the installation of lights and many other extra costs are considered at this price.

Other additional costs that are included in the wind turbine final costs are the transportation costs which were assumed to be at 3,900 Euros for each wind turbine according to the paper ‘OFFSHORE WIND: Economies of Scale, Engineering Resource and Load Factors’. This paper suggests that the cost of the wind turbine supply and the commissioning fees for a 3 MW wind turbine together with the transformer, the switchgear and the tower to give a hub height of approximately 75m, is approximately 2,400 Euros. Considering the fact that the height and weight of the 4.5 MW wind turbine that we have used for our project is much higher, and larger lorries and greater lifting capacity cranes have to be used, we used the above price but include a 65% increase of the above cost, totalling 3,900 Euro for each wind turbine.

Other extra costs of the wind turbine that were included on the RETscreen calculation sheet were the cost of the structural work of the wind turbines, meaning the use of steel for equipment such as ladders and cathodic protection, which was estimated to be a tone of steel for each wind turbine, so the final structural steel work cost was 242,000 Euros.

9.11.3 Grid connection costs

In order to estimate the grid connection costs we used the guidelines that the paper 'Seawind Feasibility study guidelines' provided.

As a result, the 150kV underwater sea cable used for the connection of the offshore wind farm with the shore which was supposed to be at a distance of 40 km from the offshore site, the cost was estimated to be 20 million Euros.

For the 30kV cable used for the connection of the wind turbines with the transformer station which was calculated to be 45 km long, the cost was 4.5 million Euros and another 400,000 Euros was the cost of placing a cable collection point at each end of the local grid connection.

2 million Euros was estimated to be the cost of using 110 wind turbines connectors with the local grid. These connectors operate under a monitoring system of power supply to the local grid. This system is known as a 'SCADA' monitoring of the supply system.

In order to transmit the electricity produced offshore to the shore, there was a need for a high voltage offshore substation. The cost of the offshore substation was considered to be equal to 15 million Euros.

Other extra costs such as the cost of cable laying and 20% of weather downtime for the cable installation were considered to have an additional cost of 2 million Euros.

The onshore costs were roughly estimated and not divided into different parts such as grid upgrade or connection with the main onshore grid transformer.

The cost of the onshore grid connection was considered to be 49.1 million Euros.

9.11.4 Cost of feasibility study

According to the bibliography, feasibility study costs include the costs of doing an Environmental Impact Assessment (EIA), site surveys and measuring campaigns, wind monitoring through the installation of a meteorological mast and so on

The price we used for the RETscreen calculation sheet was 890,000 Euros.

The cost of a years measuring campaign is estimated to be 145,000 Euros while the cost of a complete meteorological mast is equal to 370,000 Euros. A typical site survey cost together with the EIA is estimated to be approximately 375,000 Euros which makes the total cost for the feasibility study of 890,000 Euros.

9.11.5 Management costs

Management costs include the cost of further site surveys, insurances and financing costs, administration fees, project controls, reporting and monitoring.

According to the bibliography resource ‘OFFSHORE WIND: Economies of Scale, Engineering Resource and Load Factors’, the final cost of management stage is approximately 2,934,700 Euros.

9.11.6 Other cost factors

Due to the fact that we have to deal with a prototype wind turbine and a 495 MW wind park, it would be appropriate to allow a percentage of the total wind park construction costs for contingencies such as bad weather or extra costs due to unscheduled repairs or even breakdowns.

For this reason we have chosen to use an allowance of 5% of the total construction costs for the above mentioned contingencies.

According to a number of different publications, there is a need for maintenance of the wind turbines every 8760 hours of operation which is approximately once per year.

The cost of maintenance of the wind turbines according to the above reference is approximately 80,000 Euros per wind turbine per year, so allowing another 10% for maintenance contingencies, the total cost of maintenance of the wind park per year is approximately 9,680,000 Euros.

There are also some periodic costs such as drive train and blade repair or refurbishment which are included in the calculation sheet and also the cost of removing the offshore wind park from its area of installation at the end of the project life time which is considered to be approximately 9 million Euros.

9.12 Conclusions from the results of the case study

From the above case study we can see that the main disadvantage of a multi megawatt offshore wind farm is the need for high initial investment costs in order to establish the project. Of course, in our case the worst case scenario was examined as was previously mentioned but either way, the payback time was at 10.6 years. The payback time is within the limits of 10 to 15 years that the bibliography suggests. After year 12, the positive cash flow is substantial and the project starts to make a huge profit not only in terms of money but also in terms of CO_2 emission savings.

As can be seen from figures 37 and 38, the total initial costs for the construction of the wind farm were approximately 1,6 billion Euros. By year 25 as can be seen from table 37, the profit of the wind farm is more than double the initial cost and this is for a project life time of 25 years.

In order to see the actual profit of a future offshore wind farm, the life time of the wind farm was doubled and then the costs and the final profit were calculated. This is a viable option since the foundations of future offshore wind farms will be designed for a lifetime of 50 years and the wind turbines and pylons will be either replaced or refurbished after 25 years of life time. The results we obtained are presented in the figure below.

Yearly Cash Flows			
Year	Pre-tax	After-tax	Cumulative
#	€	€	€
0	(461.856.279)	(461.856.279)	(461.856.279)
1	(6.244.436)	(6.244.436)	(468.100.715)
2	527.779	527.779	(467.572.935)
3	7.624.830	7.624.830	(459.948.105)
4	15.062.612	15.062.612	(444.885.493)
5	22.306.029	22.306.029	(422.579.464)
6	30.476.152	30.476.152	(392.103.312)
7	39.039.576	39.039.576	(353.063.736)
8	48.015.584	48.015.584	(305.048.152)
9	57.424.417	57.424.417	(247.623.735)
10	64.727.147	64.727.147	(182.896.587)
11	77.626.576	77.626.576	(105.270.011)
12	88.465.595	88.465.595	(16.804.416)
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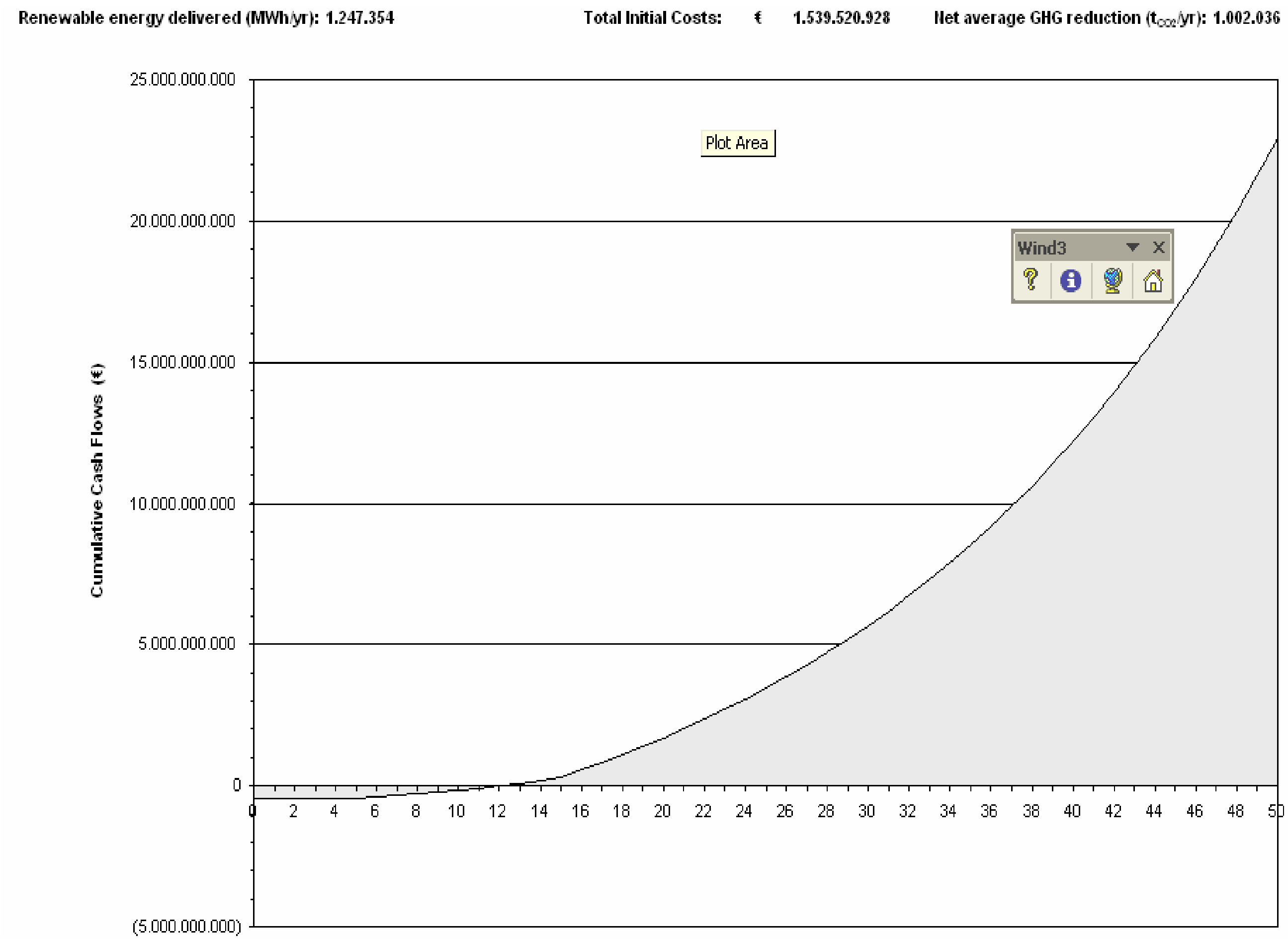
14	111.742.357	111.742.357	194.766.870
15	121.336.331	121.336.331	316.103.202
16	249.263.720	249.263.720	565.366.922
17	261.837.855	261.837.855	827.204.777
18	275.049.677	275.049.677	1.102.254.454
19	288.931.297	288.931.297	1.391.185.751
20	300.239.200	300.239.200	1.691.424.951
21	318.840.498	318.840.498	2.010.265.449
22	329.974.643	329.974.643	2.340.240.092
23	346.889.995	346.889.995	2.687.130.087
24	364.661.531	364.661.531	3.051.791.618
25	383.332.319	383.332.319	3.435.123.937
26	402.947.589	402.947.589	3.838.071.526
27	423.554.840	423.554.840	4.261.626.366
28	445.203.949	445.203.949	4.706.830.315
29	467.947.299	467.947.299	5.174.777.614
30	483.449.624	483.449.624	5.658.227.237
31	516.939.500	516.939.500	6.175.166.737
32	543.306.777	543.306.777	6.718.473.514
33	571.005.425	571.005.425	7.289.478.939
34	600.102.338	600.102.338	7.889.581.277
35	630.667.763	630.667.763	8.520.249.040
36	662.775.467	662.775.467	9.183.024.506
37	696.502.913	696.502.913	9.879.527.420
38	731.931.449	731.931.449	10.611.458.869
39	769.146.497	769.146.497	11.380.605.366
40	802.867.631	802.867.631	12.183.472.997
41	849.299.432	849.299.432	13.032.772.430
42	892.430.434	892.430.434	13.925.202.864
43	937.734.637	937.734.637	14.862.937.500
44	985.321.116	985.321.116	15.848.258.617
45	1.029.228.607	1.029.228.607	16.877.487.224
46	1.087.804.807	1.087.804.807	17.965.292.031
47	1.142.948.599	1.142.948.599	19.108.240.630
48	1.200.868.420	1.200.868.420	20.309.109.050
49	1.261.703.541	1.261.703.541	21.570.812.591
50	1.348.986.670	1.348.986.670	22.919.799.262

Table 40: Yearly cash flows for a project life time of 50 years



Renewable energy delivered (MWh/yr): 1.247.354 Total Initial Costs: € 1.539.520.928 Net average GHG reduction (t_{CO2}/yr): 1.002.036

Table 41: Graphical output of cumulative cash flows for a project life time of 50 years

From the above tables it can be seen that the profit of such a wind farm design will be more than 5 times the initial expenses. Therefore although it has a late payback time, the result is a very profitable and clean source of electricity supply.

The main reason for making an offshore wind park like the one examined profitable is the use of multi megawatt wind turbines. A considerable part of the increase in cost effectiveness of the wind park is due to the increased efficiency of the wind turbine which is able to have higher production per swept rotor area at a specific wind speed when compared with smaller wind turbines. Optimizing the wind turbines will help to increase the production efficiency and thus lower the cost per KWh.

In our case, for the above case study, due to the immature design of the 4.5 MW wind turbine and due to the fact that building a 495 MW offshore wind farm is not so common, we considered having high losses either from the wind turbine array losses or from energy transportation through the cables. These assumptions can be found in table 28. Although we considered having such high losses, the unadjusted energy production was 1,658,519 MWh and the final renewable energy delivered was 1,247,354 MWh which is approximately 25% lower due to the above mentioned losses.

Considering the fact that Greece's fuel mix was previously based on coal by 90%, on hydro by 9% and on solar by 1% only, the greenhouse emissions from the use of wind energy account for 12 % reduction leading to a net annual greenhouse emission reduction of 1,103,564 tones of CO_2.

For our case study, since Greece is one of the smallest European countries, we considered that for the construction of the specific wind farm site, we would need a 15 year loan with an interest rate of 12%. Greece would provide 30% of the original expenses and the European Union would provide the other 70%. Imagine how much greater the profit would be if we had not considered using a 15 year loan.

The energy production cost of the above site is 0.0899 Eurocents.

Concerning the income side of the cash flow, in order to get the above energy production cost, the assumptions below were made.

The cost of 0,0899 Eurocents can easily increase or decrease, if there is a change at the financial parameters shown in table 36. The above value was calculated, using the assumption of 0,025 Euros/KWh renewable energy production credit for the first 15 years of operation.

Another assumption used was the Green House Gas emission credit of 5 Euros/ tonne of CO_2 reduction, for the first 21 years of operation of the wind park.

Danish pilot offshore projects have a power production cost of 0.06 to 0.08 Eurocents per kWh. This price per kWh is for offshore projects situated in water depths of up to 20 m and by using common technology such as 2 MW wind turbines. According to a recent study made by the German Wind Energy Institute on behalf of the German Engineering Federation, it was calculated that for a 450 MW offshore wind park placed at approximately 20 to 40 km offshore the power production costs would be between 0.074 to 0.081 Eurocents per kWh by using 2 MW wind turbines[23].

Considering the fact that the latest wind turbine technology of 4.5 MW was used, the power production cost of 0.089 Eurocents per kWh that we estimated from our case study seems to be realistic since we have used state of the art technology that will be in mass production in approximately 5 years from today. Until that period, the technology of the 4.5 MW wind turbine will be optimized, thus reducing the maintenance costs and the extra cost of foundations for deep sea water will be counterbalanced by the optimized production efficiency of the wind turbines.

Recycling of wind turbines and foundations at the end of their life time, either at 25 or 50 years can help to reduce the electricity production cost even more (up to 16.7%) as can be seen from the figure below.

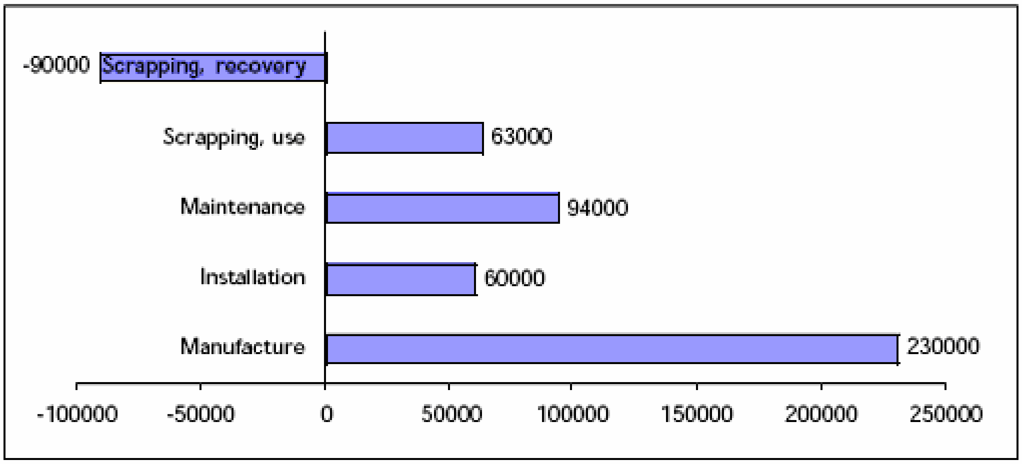
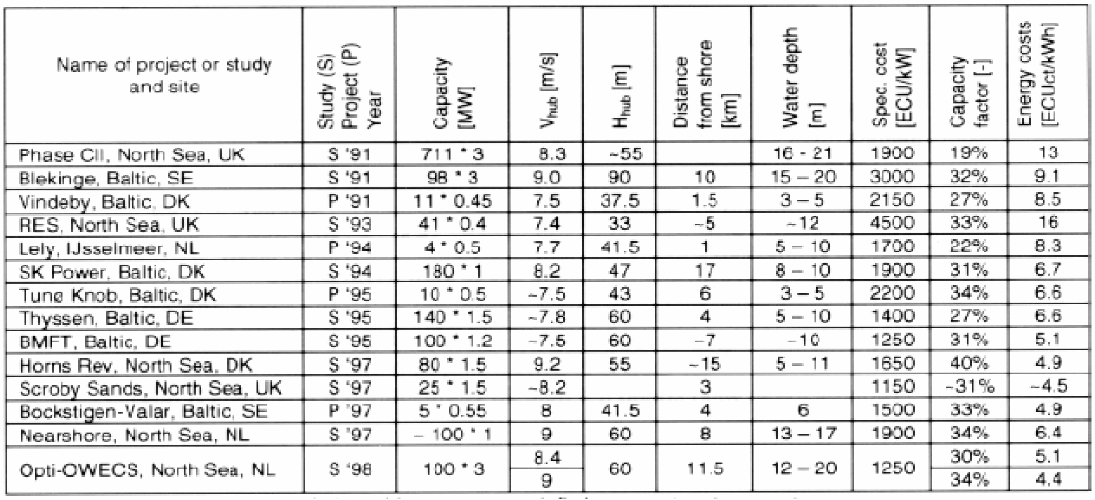


Table 42: Energy usage recalculated to kWh electricity (Net energy use)

In the table below the actual cost per kW for a number of studies or projects can be seen.

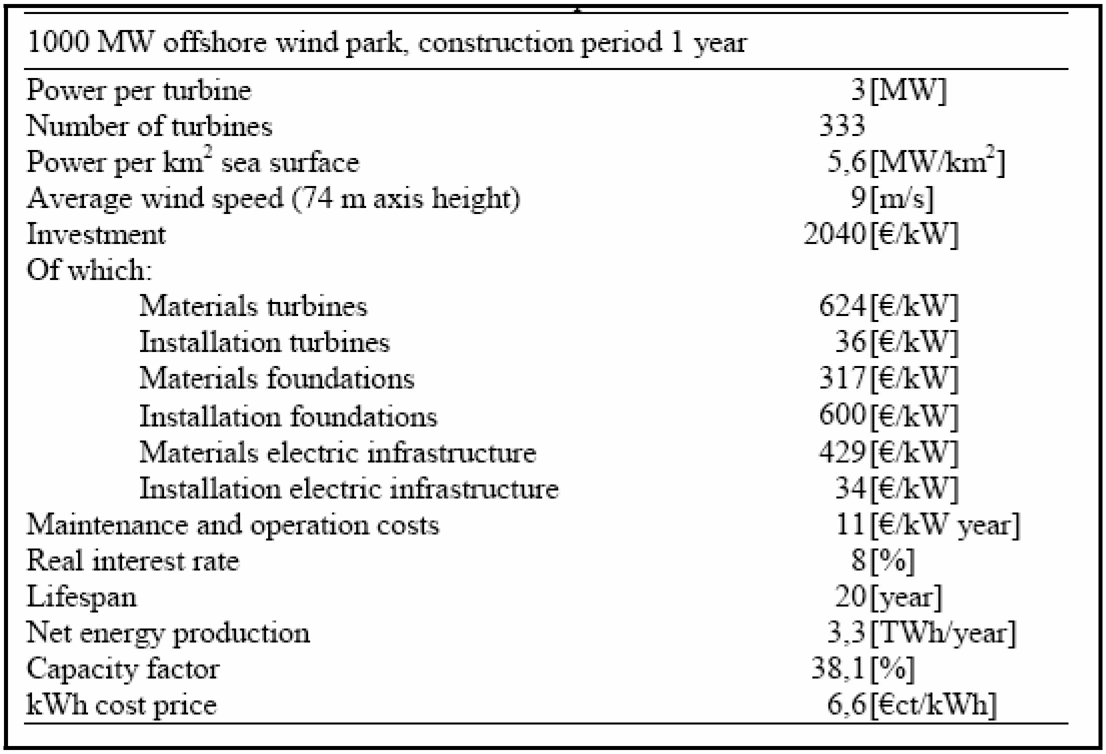


Name of project or study and site	Study (S) Project (P) Year	Capacity [MW]	V_{hub} [m/s]	H_{hub} [m]	Distance from shore [km]	Water depth [m]	Spec. cost [ECU/kW]	Capacity factor [-]	Energy costs [ECUct/kWh]
Phase CII, North Sea, UK	S '91	711 * 3	8.3	~55		16 - 21	1900	19%	13
Blekinge, Baltic, SE	S '91	98 * 3	9.0	90	10	15 – 20	3000	32%	9.1
Vindeby, Baltic, DK	P '91	11 * 0.45	7.5	37.5	1.5	3 – 5	2150	27%	8.5
RES, North Sea, UK	S '93	41 * 0.4	7.4	33	~5	~12	4500	33%	16
Lely, IJsselmeer, NL	P '94	4 * 0.5	7.7	41.5	1	5 – 10	1700	22%	8.3
SK Power, Baltic, DK	S '94	180 * 1	8.2	47	17	8 – 10	1900	31%	6.7
Tunø Knob, Baltic, DK	P '95	10 * 0.5	~7.5	43	6	3 – 5	2200	34%	6.6
Thyssen, Baltic, DE	S '95	140 * 1.5	~7.8	60	4	5 – 10	1400	27%	6.6
BMFT, Baltic, DE	S '95	100 * 1.2	~7.5	60	~7	~10	1250	31%	5.1
Horns Rev, North Sea, DK	S '97	80 * 1.5	9.2	55	~15	5 – 11	1650	40%	4.9
Scroby Sands, North Sea, UK	S '97	25 * 1.5	~8.2		3		1150	~31%	~4.5
Bockstigen-Valar, Baltic, SE	P '97	5 * 0.55	8	41.5	4	6	1500	33%	4.9
Nearshore, North Sea, NL	S '97	~ 100 * 1	9	60	8	13 – 17	1900	34%	6.4
Opti-OWECS, North Sea, NL	S '98	100 * 3	8.4	60	11.5	12 – 20	1250	30%	5.1
			9					34%	4.4

Table 43: Comparison of various studies of offshore wind energy[24]

We can see that the price that we obtained from table 28 that was equal to 2,862.5 Euros/kW, is considered to be again a logical price per kW for the extent of our project. From the table above we can see that for the Tuno Knob offshore wind park the cost per kW was equal to 2,200 Euros/kW and it was just a 5 MW project placed at 5 meters water depth. For the Vindenby offshore wind farm at Baltic Sea the cost/kW was equal to 2150 Euros/kW but again it had to deal with water depths of between 3 and 5 meters and had a capacity of 5 MW. On the other hand, Horns Rev offshore wind park has a capacity of 160 MW and a cost of approximately 1650 Euros/ kW although it is placed in water depths of up to 11 m deep. The reason for that is probably the reduction of the cost of the wind turbines with time, especially if we are working with average technology wind turbines such as the 2 MW wind turbines used for Horns Rev. These prices show the bottom line of our project.

On the other hand, in Noords, a 1000 MW offshore wind farm costs are described. The costs are shown in the table below.



1000 MW offshore wind park, construction period 1 year		
Power per turbine	3	[MW]
Number of turbines	333	
Power per km^2 sea surface	5,6	[MW/km^2]
Average wind speed (74 m axis height)	9	[m/s]
Investment	2040	[€/kW]
Of which:		
Materials turbines	624	[€/kW]
Installation turbines	36	[€/kW]
Materials foundations	317	[€/kW]
Installation foundations	600	[€/kW]
Materials electric infrastructure	429	[€/kW]
Installation electric infrastructure	34	[€/kW]
Maintenance and operation costs	11	[€/kW year]
Real interest rate	8	[%]
Lifespan	20	[year]
Net energy production	3,3	[TWh/year]
Capacity factor	38,1	[%]
kWh cost price	6,6	[€ct/kWh]

Table 44: Characteristics of a 1000MW offshore wind in 2010[25]

According to Noord, the cost per kW, for a 1000 MW offshore wind park positioned 10 km from shore and at water depths between 20 and 50 m deep, will be approximately

2040 Euro/kW by the year 2010 and the cost of each KWh is calculated to be equal to 6.6 Eurocents/ kW.

In our case the costs were 2,862.5 Euros/kW and 8.9 Eurocents/kW. Due to the decreasing trend of the price of the wind turbines, the above example of the 1000MW wind park seems to be the actual figure of the future cost of offshore wind turbines. By the year 2010 deep offshore wind farms will be mature technology so the cost of installation of a wind park per kW will be reduced from approximately 2,900 Euros to 2,000 Euros and the cost of KWh is going to be reduced from 0.089 Euros to 0.066 Euros per KWh.

Comparing the cost analysis of our 495 MW offshore wind farm with the one presented in figure 38 for a 150 MW wind farm, some valuable information about the difference in the costs of an offshore wind farm with a deep offshore wind farm can be obtained.

In our case study our main costs were the cost of the foundations and the cost of the wind turbines. This is the area that needs further development in order to make deep offshore wind farms a feasible option for economical power production. The cost of grid connection, maintenance and the cost of doing a feasibility study and development are negligible compared with the expenses needed for the construction of the deep offshore foundations and the wind turbines.

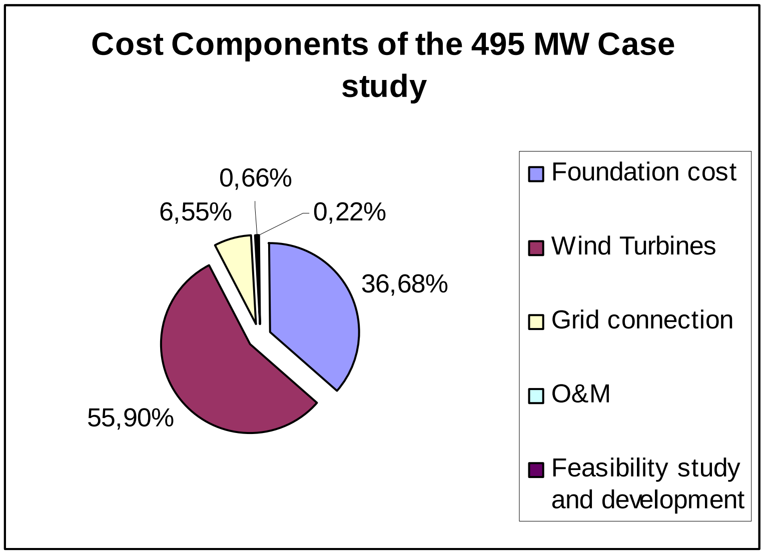
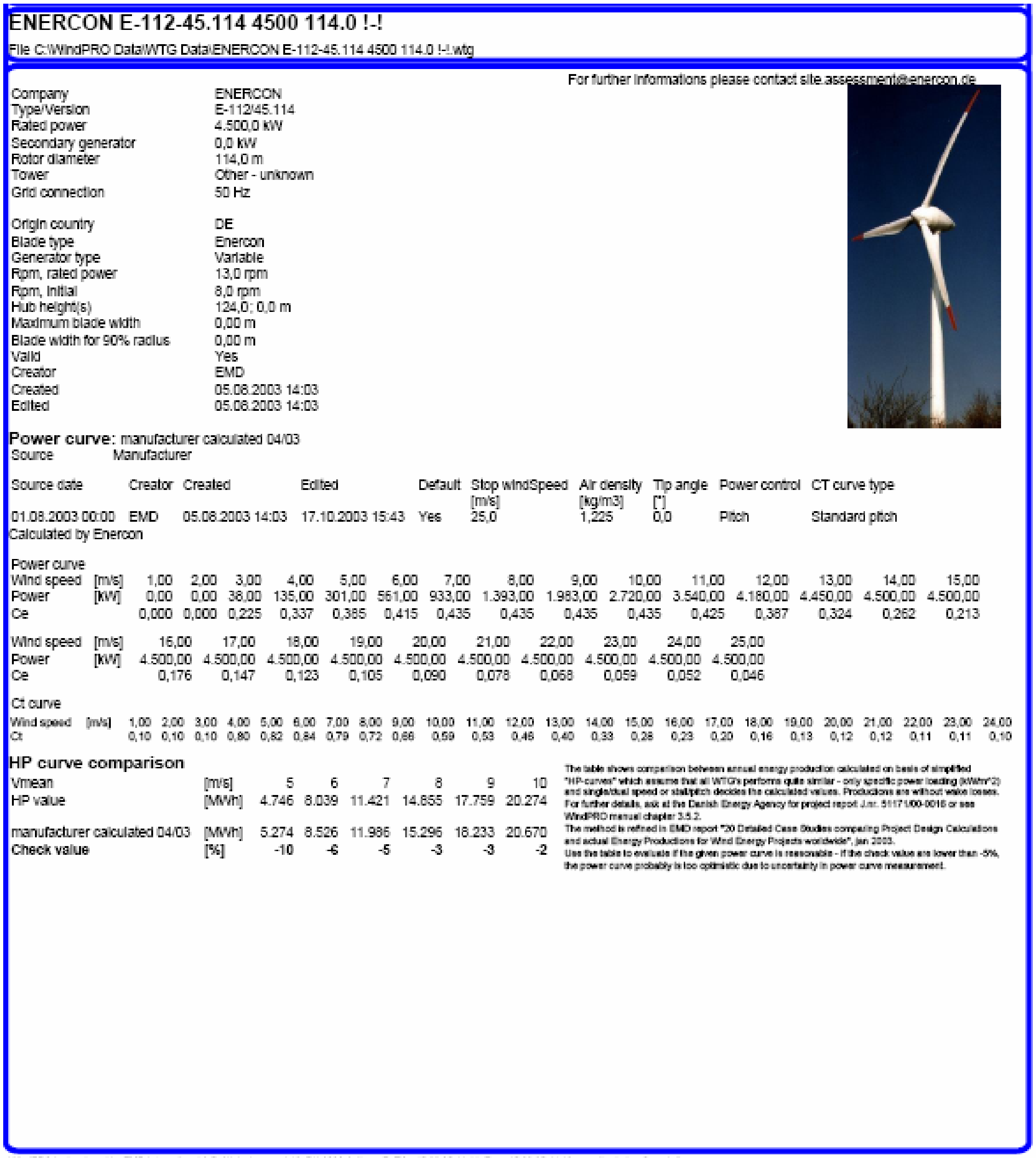


Table 45: Cost distribution for a 495 MW deep offshore wind park

Further development at the fields of multi-Megawatt wind turbine technology and foundations will create powerful tools towards fossil fuel independence, providing both on-grid and off-grid communities with clean electricity, at the minimum cost.

Appendix 1



ENERCON E-112-45.114 4500 114.0 !-!

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For further informations please contact site.assessment@enercon.de

Company	ENERCON
Type/Version	E-112/45.114
Rated power	4.500,0 kW
Secondary generator	0,0 kW
Rotor diameter	114,0 m
Tower	Other - unknown
Grid connection	50 Hz
Origin country	DE
Blade type	Enercon
Generator type	Variable
Rpm, rated power	13,0 rpm
Rpm, initial	8,0 rpm
Hub height(s)	124,0; 0,0 m
Maximum blade width	0,00 m
Blade width for 90% radius	0,00 m
Valid	Yes
Creator	EMD
Created	05.08.2003 14:03
Edited	05.08.2003 14:03

Power curve: manufacturer calculated 04/03

Source Manufacturer

Source date	Creator	Created	Edited	Default	Stop windSpeed [m/s]	Air density [kg/m3]	Tip angle [°]	Power control	CT curve type
01.08.2003 00:00	EMD	05.08.2003 14:03	17.10.2003 15:43	Yes	25,0	1,225	0,0	Pitch	Standard pitch

Calculated by Enercon

Power curve

Wind speed	[m/s]	1,00	2,00	3,00	4,00	5,00	6,00	7,00	8,00	9,00	10,00	11,00	12,00	13,00	14,00	15,00
Power	[kW]	0,00	0,00	38,00	135,00	301,00	561,00	933,00	1.393,00	1.983,00	2.720,00	3.540,00	4.180,00	4.450,00	4.500,00	4.500,00
Ce		0,000	0,000	0,225	0,337	0,385	0,415	0,435	0,435	0,435	0,435	0,425	0,387	0,324	0,262	0,213

Wind speed	[m/s]	16,00	17,00	18,00	19,00	20,00	21,00	22,00	23,00	24,00	25,00
Power	[kW]	4.500,00	4.500,00	4.500,00	4.500,00	4.500,00	4.500,00	4.500,00	4.500,00	4.500,00	4.500,00
Ce		0,176	0,147	0,123	0,105	0,090	0,078	0,068	0,059	0,052	0,046

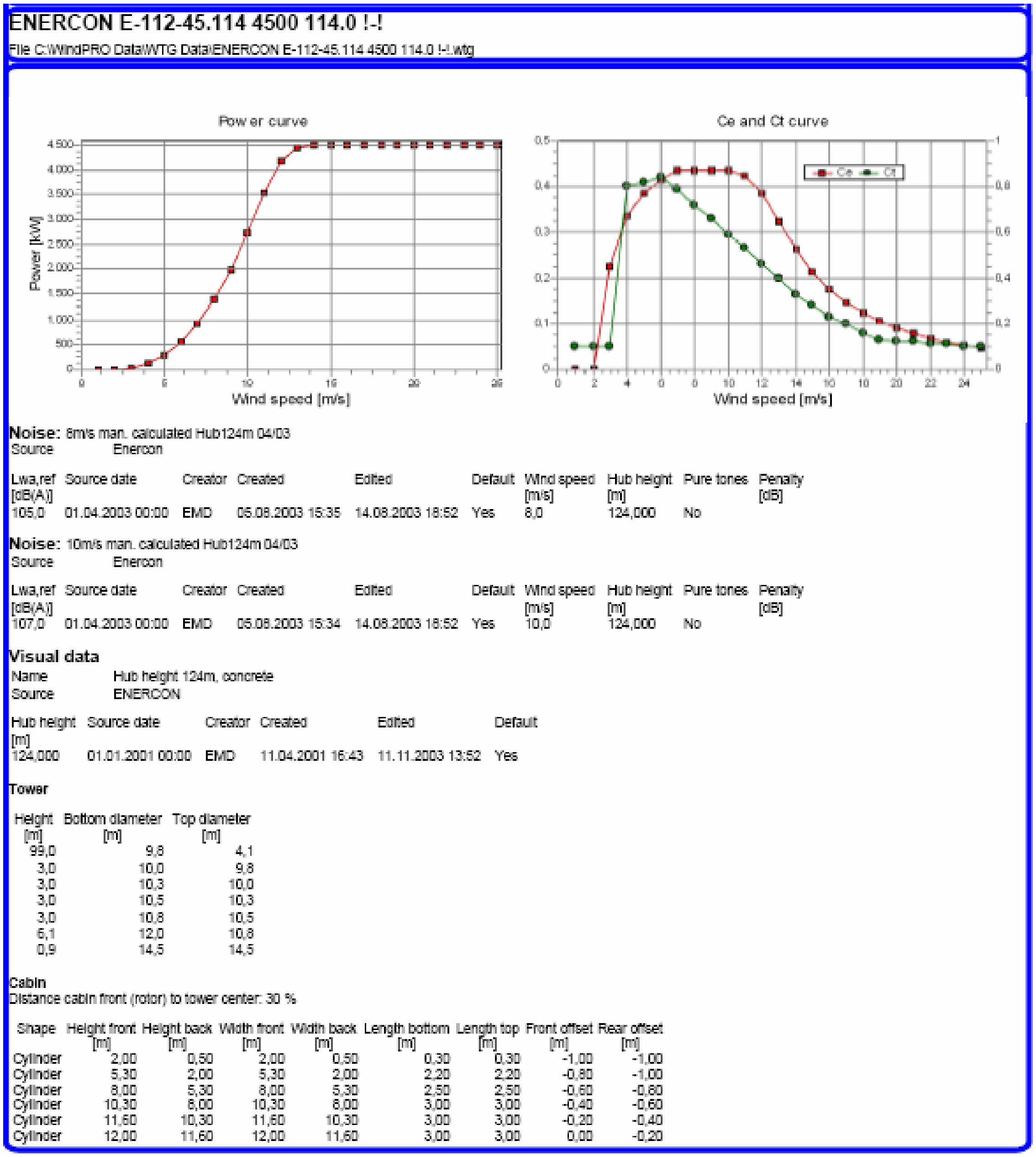
Ct curve

Wind speed	[m/s]	1,00	2,00	3,00	4,00	5,00	6,00	7,00	8,00	9,00	10,00	11,00	12,00	13,00	14,00	15,00	16,00	17,00	18,00	19,00	20,00	21,00	22,00	23,00	24,00
Ct		0,10	0,10	0,10	0,80	0,82	0,84	0,79	0,72	0,66	0,59	0,53	0,46	0,40	0,33	0,28	0,23	0,20	0,16	0,13	0,12	0,12	0,11	0,11	0,10

HP curve comparison

Vmean	[m/s]	5	6	7	8	9	10
HP value	[MWh]	4.746	8.039	11.421	14.655	17.759	20.274
manufacturer calculated 04/03	[MWh]	5.274	8.526	11.986	15.296	18.233	20.670
Check value	[%]	-10	-6	-5	-3	-3	-2

The table shows comparison between annual energy production calculated on basis of simplified "HP-curves" which assume that all WTG's performs quite similar - only specific power loading (kW/m^2) and single/dual speed or stall/pitch decides the calculated values. Productions are without wake losses. For further details, ask at the Danish Energy Agency for project report J.nr. 51171/00-0016 or see WindPRO manual chapter 3.5.2.
The method is refined in EMD report "20 Detailed Case Studies comparing Project Design Calculations and actual Energy Productions for Wind Energy Projects worldwide", jan 2003.
Use the table to evaluate if the given power curve is reasonable - if the check value are lower than -5%, the power curve probably is too optimistic due to uncertainty in power curve measurement.



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Noise: 8m/s man. calculated Hub124m 04/03
Source Enercon

Lwa,ref [dB(A)]	Source date	Creator	Created	Edited	Default	Wind speed [m/s]	Hub height [m]	Pure tones	Penalty [dB]
105,0	01.04.2003 00:00	EMD	05.08.2003 15:35	14.08.2003 18:52	Yes	8,0	124,000	No	

Noise: 10m/s man. calculated Hub124m 04/03
Source Enercon

Lwa,ref [dB(A)]	Source date	Creator	Created	Edited	Default	Wind speed [m/s]	Hub height [m]	Pure tones	Penalty [dB]
107,0	01.04.2003 00:00	EMD	05.08.2003 15:34	14.08.2003 18:52	Yes	10,0	124,000	No	

Visual data

Name Hub height 124m, concrete
Source ENERCON

Hub height [m]	Source date	Creator	Created	Edited	Default
124,000	01.01.2001 00:00	EMD	11.04.2001 16:43	11.11.2003 13:52	Yes

Tower

Height [m]	Bottom diameter [m]	Top diameter [m]
99,0	9,8	4,1
3,0	10,0	9,8
3,0	10,3	10,0
3,0	10,5	10,3
3,0	10,8	10,5
6,1	12,0	10,8
0,9	14,5	14,5

Cabin

Distance cabin front (rotor) to tower center: 30 %

Shape	Height front [m]	Height back [m]	Width front [m]	Width back [m]	Length bottom [m]	Length top [m]	Front offset [m]	Rear offset [m]
Cylinder	2,00	0,50	2,00	0,50	0,30	0,30	-1,00	-1,00
Cylinder	5,30	2,00	5,30	2,00	2,20	2,20	-0,80	-1,00
Cylinder	8,00	5,30	8,00	5,30	2,50	2,50	-0,60	-0,80
Cylinder	10,30	8,00	10,30	8,00	3,00	3,00	-0,40	-0,60
Cylinder	11,60	10,30	11,60	10,30	3,00	3,00	-0,20	-0,40
Cylinder	12,00	11,60	12,00	11,60	3,00	3,00	0,00	-0,20

ENERCON E-112-45.114 4500 114.0 !-!

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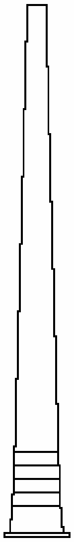
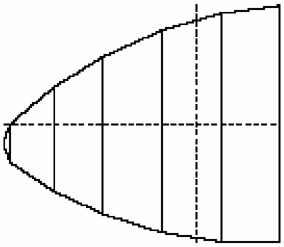
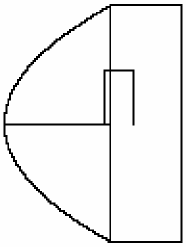
Rotor and hub

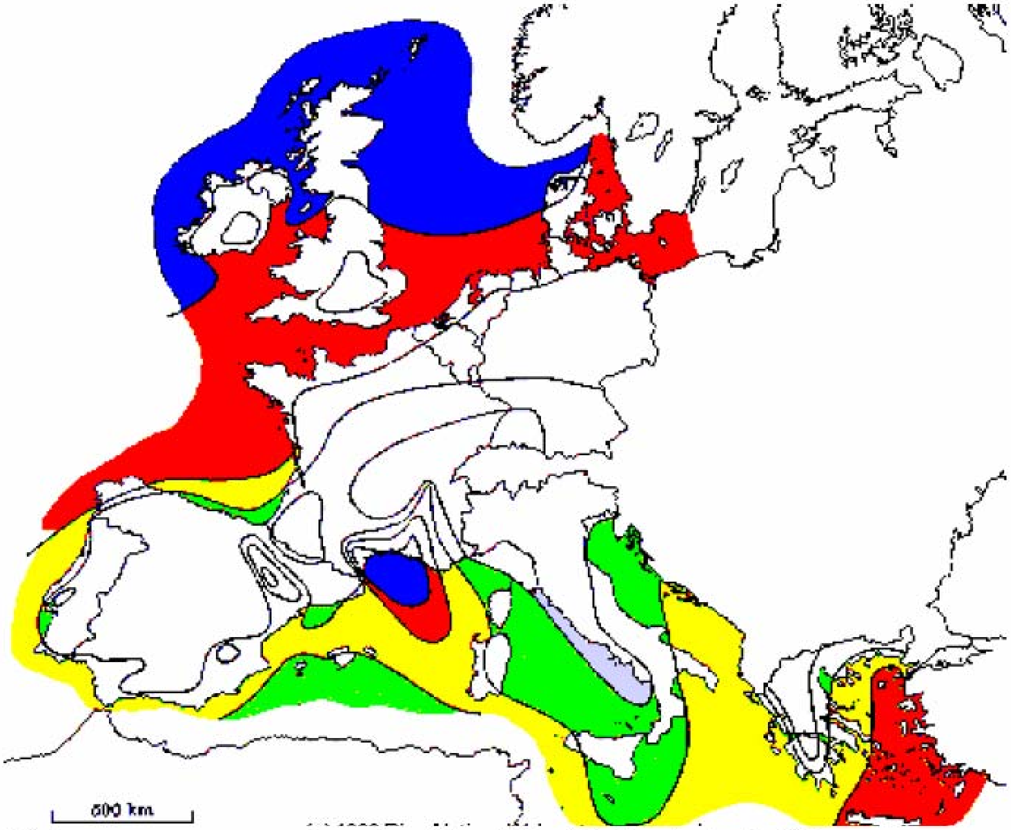
Number of blades	3
Blade position (center to cabin)	3,20 m
Chord max	5,80 m
Rotor position relative to tower	Up wind
Hub length (cabin to spinner tip)	9,00 m
Spinner length (0 = no spinner)	5,40 m
Hub diameter (2xradius from hub center to blade root)	5,50 m
Spinner max diameter	12,00 m
Shaft radius	12,00 m
Hub tilt angle	4,0 °
Blade cone angle	0,0 °



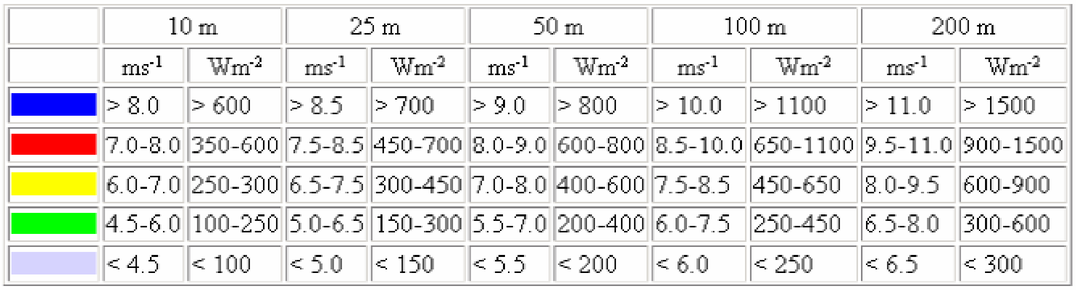




Appendix 2



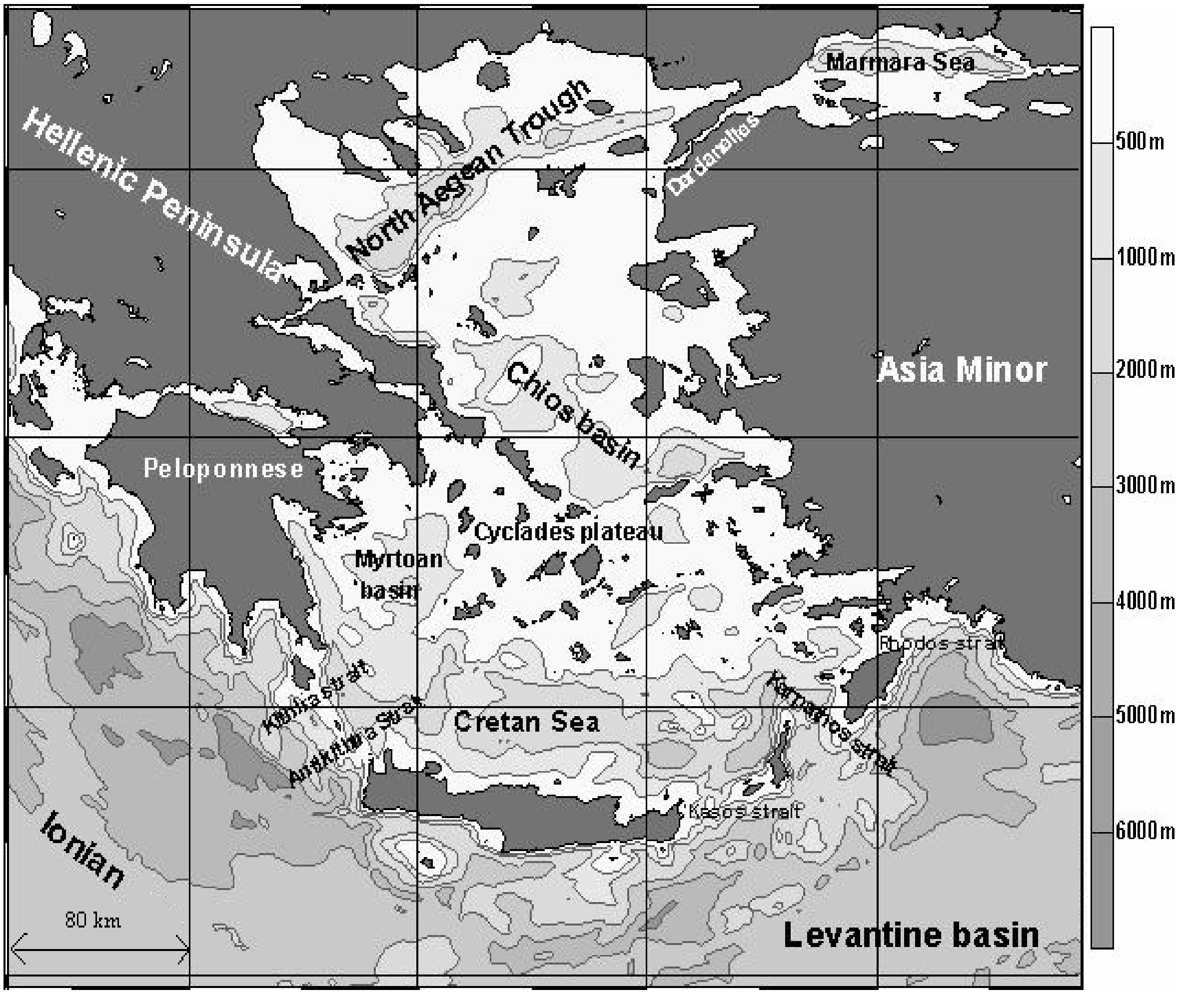
Wind resources over open sea (more than 10 km offshore) for five standard heights.



	10 m		25 m		50 m		100 m		200 m	
	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}
🟦	> 8.0	> 600	> 8.5	> 700	> 9.0	> 800	> 10.0	> 1100	> 11.0	> 1500
🟥	7.0-8.0	350-600	7.5-8.5	450-700	8.0-9.0	600-800	8.5-10.0	650-1100	9.5-11.0	900-1500
🟨	6.0-7.0	250-300	6.5-7.5	300-450	7.0-8.0	400-600	7.5-8.5	450-650	8.0-9.5	600-900
🟩	4.5-6.0	100-250	5.0-6.5	150-300	5.5-7.0	200-400	6.0-7.5	250-450	6.5-8.0	300-600
⬜	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 6.0	< 250	< 6.5	< 300

European Wind Atlas

Appendix 3



Basic topographic features of the Aegean Sea region

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