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Project of Offshore Wind Energy: Research, Experimentation, Development

WP 3 - TASK 3.1

Technological State of the Art

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1 Introduction

The POWERED project - "Offshore Wind Energy: Research, Experimentation, Development" is aimed to define common strategies and methods for the offshore wind energy development in all countries bordering the Adriatic Sea.

This report is part of WP3 - "Technological, Environmental policies and regulations of Energetic state of the art" and concerns the Task 3.1 - "Technological state of the art". The aim is to define the best existing technologies in order to realize offshore wind farms in the Adriatic sea, underlining energy production capabilities, main dimensions, materials and reliability.

Paragraph 2 illustrates the **offshore wind energy overview**, analyzing the offshore wind in terms of turbines size, distance from shore, water depth and wind farms size as well as future trends. It examines how the wind power capacity installed is evolved in EU and in the rest of the world, with a particular reference to the offshore wind energy. The most important under construction and active offshore wind farms are analyzed, including the costs and the offshore wind energy scenarios for 2020 and 2030.

Paragraph 3 illustrates the **Off-shore wind energy technological and physical limits**. In particular, it analyzes the Adriatic Sea environmental conditions, as the general climatology and the bathymetric maps. Then, the different types of foundations and support structures and the requirements to design an offshore wind project are illustrated. Furthermore, the main manufacturers of offshore wind turbines and the turbine models are reported, as well as the wind conditions and Wind Turbine Classes. The paragraph examines the offshore grid connection requirements and technologies, including the power control and the electricity storage systems. Finally, the wind energy LCA (Life cycle assessment) studies, carried out within the ECLIPSE project, are reported.

Paragraph 4 describes the **technologies and materials** to realize offshore wind turbines components. Some of the analyzed components are the blades, nacelle cover, spinner, towers and cables.

Paragraph 5 illustrates the state of the art from a **technological, industrial and infrastructural point of view**. The techniques adopted for the meteorological, geological and marine data measurement, such as wind speed and its directions, water depths, waves, tides and currents are reported. Moreover the section analyses the wind turbine transport and installation procedures, including submarine cabling requirements along with the installation procedures and the laying operation. Finally, the concept of reliability and the different steps to perform a reliability analysis is illustrated. In particular the different maintenance strategies are described.

The analysis was conducted focusing on the most important methods used to identify the causes and the consequences of a failure event, how failures can be prevented and how to improve the availability of a system.

Paragraph 6 illustrates the **disused offshore platforms** requirements to house a weather station: the required area of the platform to place the tower, the mast geometric characteristics and the design loads. In appendix B the disused offshore platforms and their characteristics, as general data, dimensions and sites information are reported.

Figure 1 shows a schematic representation of the topics investigated and described in this report.

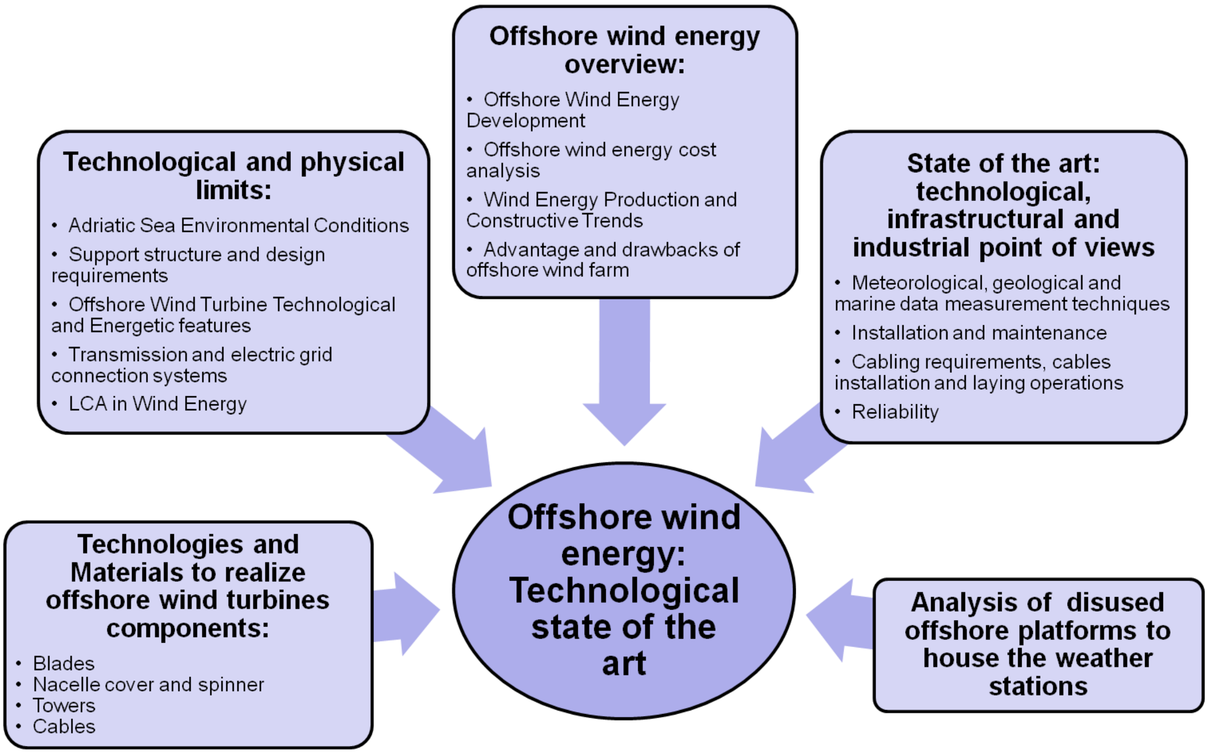


Figure 1 Offshore wind energy technological state of the art: topics investigated

2 Offshore wind energy overview

2.1 Offshore Wind Energy Development

The first documented offshore wind turbine concept was developed by Hermann Honnef in Germany in the thirties of the twentieth century (Figure 2) ([1.]).

Instead the first detailed study of a wind farm was built in the seventies by William Heronemus University of Massachusetts (Figure 3).

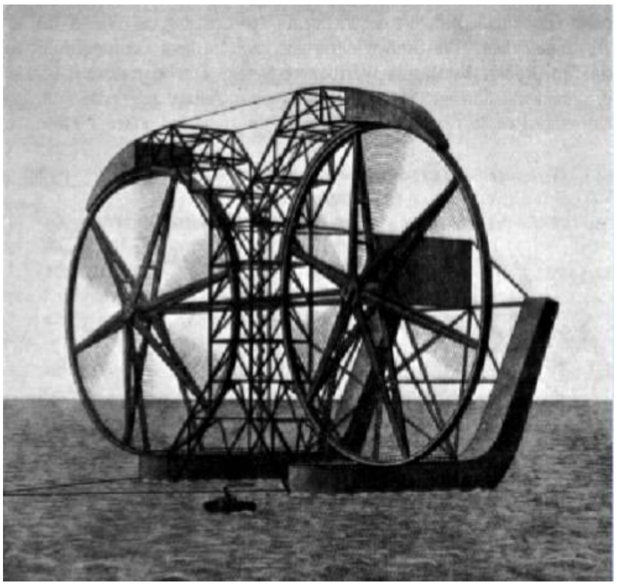


Figure 2 Offshore multi-rotor designed by Hermann Honnef in 1932.

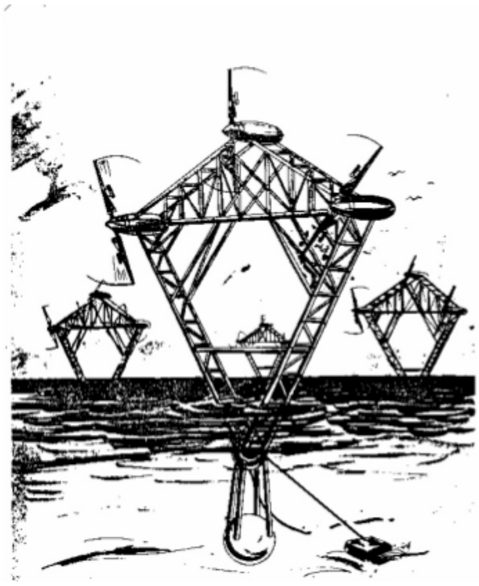


Figure 3 The wind farm planned by Heronemus in 1972.

Heronemus had the great merit of conceiving large-scale energy production just before the rebirth of the modern wind turbine.

In his study Heronemus imagined hundreds of floating wind turbines off the east coast of the United States, but actually only in the early nineties, after the success of onshore wind turbines, the scientific community was back to deal with offshore wind ([2.]).

In 1990, 18 years after Heronemus' idea, the first modern wind turbine (with a capacity of 220 kW) was installed at Nogersund in Sweden, 250 m from shore in 7 m deep water.

In 1991 Denmark began to produce energy through the first offshore wind farm in the world.

Figure 4 The first wind farm in Denmark, Vindeby.

This is a wind farm consisting of 11 wind turbines, each with a nominal power of 450 kW, hence with a total size of 4.95 MW. The wind farm is placed 3 km from the coast, near the municipality of Vindeby, in shallow (2-5 m) and protected water.

Subsequently offshore turbines were installed in the Netherlands, United Kingdom, Sweden, Ireland, Germany, China and Japan ([3.]).

Over the years, research and development of offshore wind technology has enabled the following improvements ([4.]):

- increasing size of wind turbines (Figure 5);
- increasing distance from shore and deeper water of wind farms (Figure 6, Figure 7);
- wind farms increasingly large and complex (Figure 8).

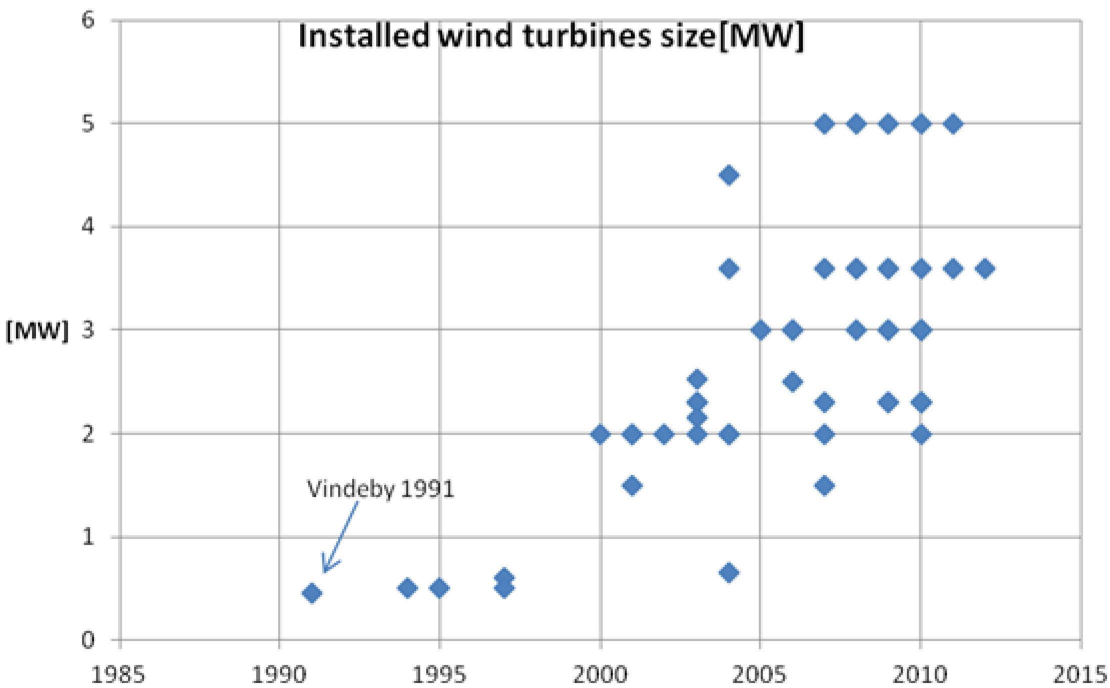


Figure 5 Offshore wind turbines rated power over time.

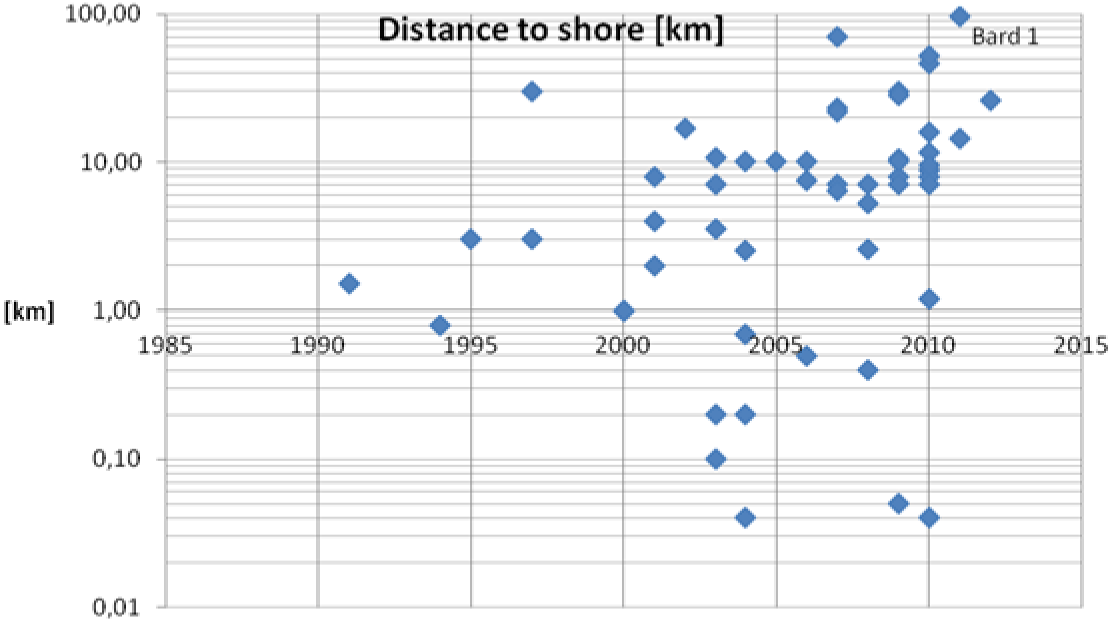


Figure 6 Offshore wind farms distance to shore over time.

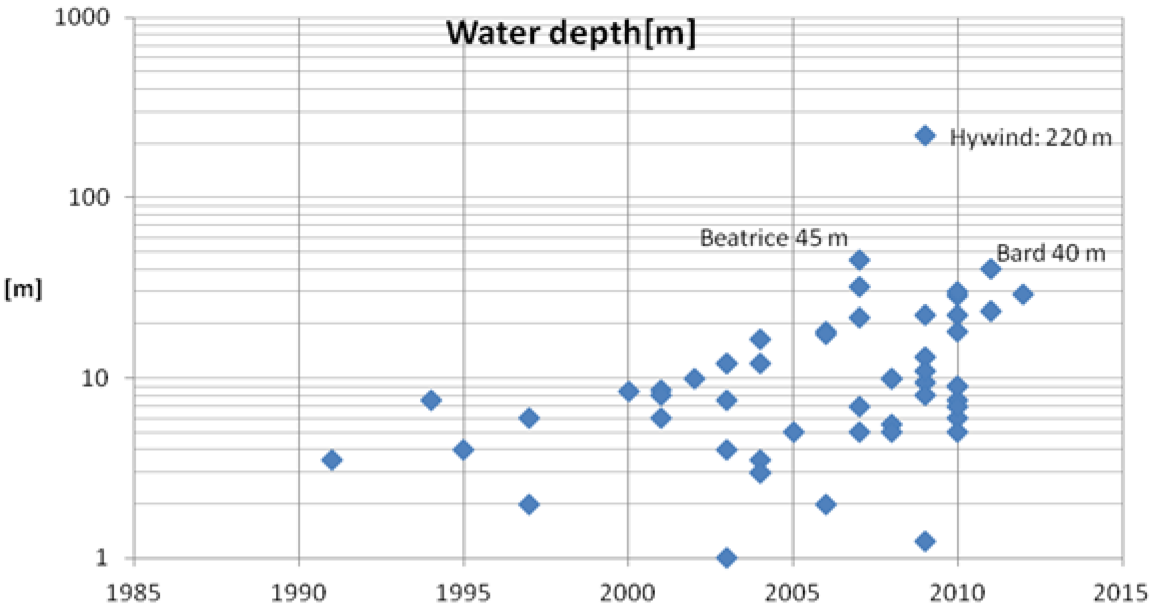


Figure 7 Offshore wind farms water depth over time.

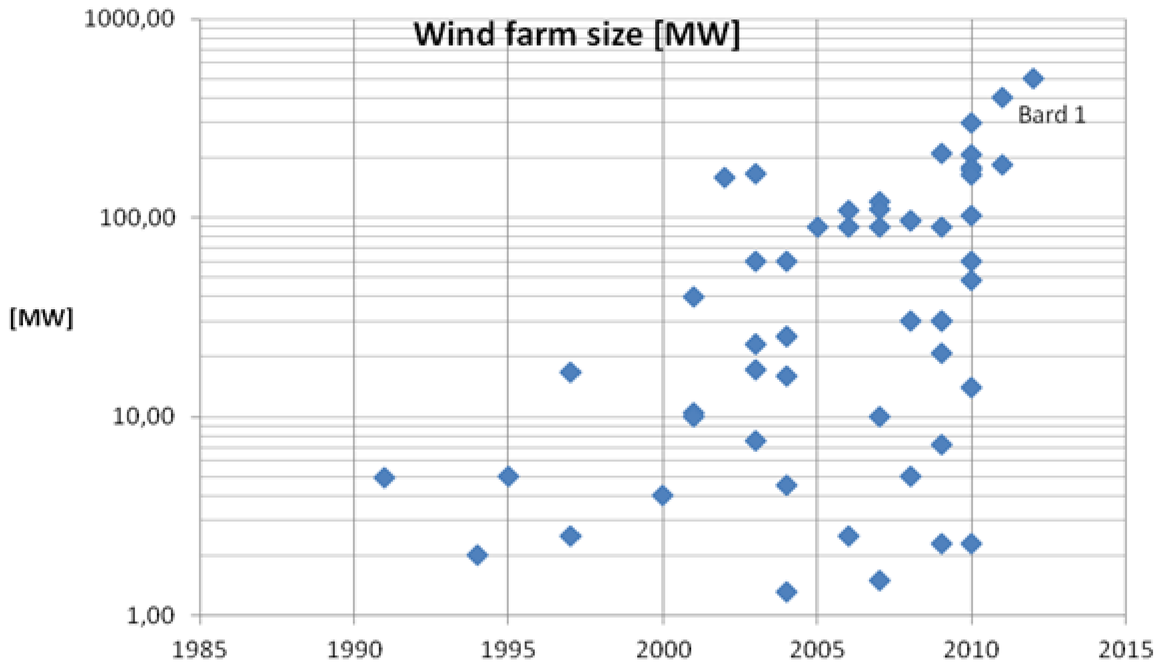
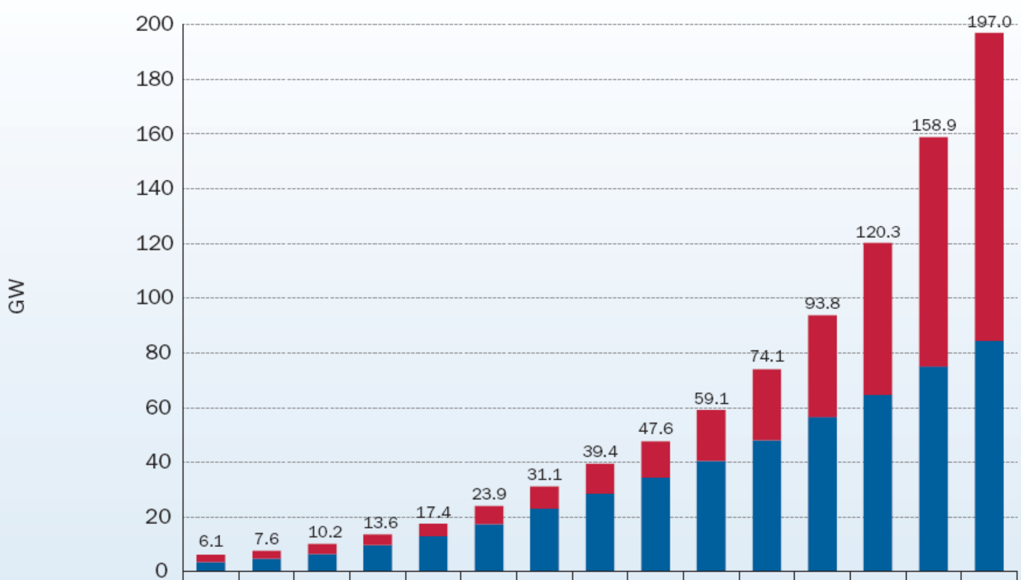


Figure 8 Offshore wind farms installed capacity over time.

2.1.1 The status of wind energy in recent years (2010-2014)

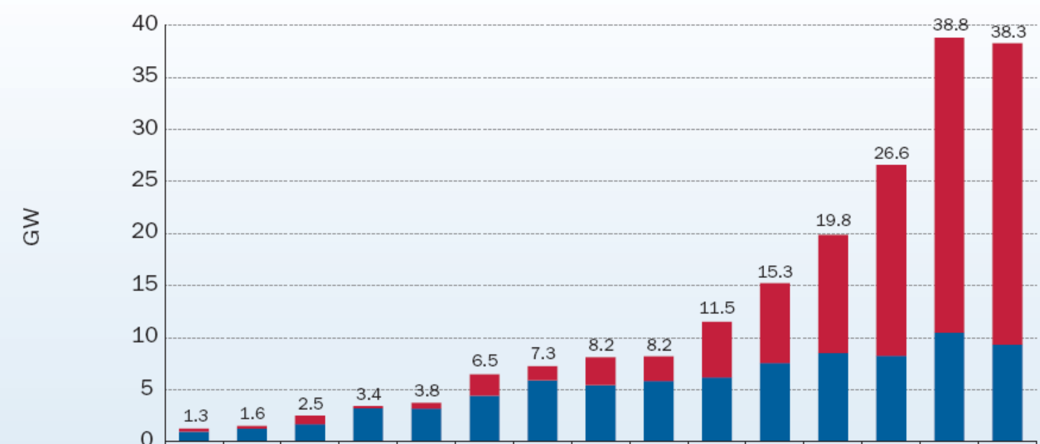
At end 2010, wind energy meets 5.3% of the EU's electricity consumption from an installed capacity of 84.3 GW (Figure 10); 38.3 GW of wind power capacity was installed globally, reaching a total of 197 GW by the end of the year (Figure 9). The global annual market for wind turbines decreased by 1.3% in 2010, following growth of 46% in 2009, 37% in 2008 and 31% in 2007 (Figure 10) ([5.]).



	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Rest of the world	2.6	2.8	3.7	3.9	4.5	6.6	8.0	10.9	13.2	18.6	26.0	37.3	55.6	83.8	112.7
EU	3.5	4.8	6.5	9.7	12.9	17.3	23.1	28.5	34.4	40.5	48.0	56.5	64.7	75.1	84.3
Total	**6.1**	**7.6**	**10.2**	**13.6**	**17.4**	**23.9**	**31.1**	**39.4**	**47.6**	**59.1**	**74.1**	**93.8**	**120.3**	**158.9**	**197**

Source: "Global wind report – annual market update 2010" – GWEC 2011; EWEA 2011

Figure 9 Global cumulative wind power capacity (1996 – 2010)

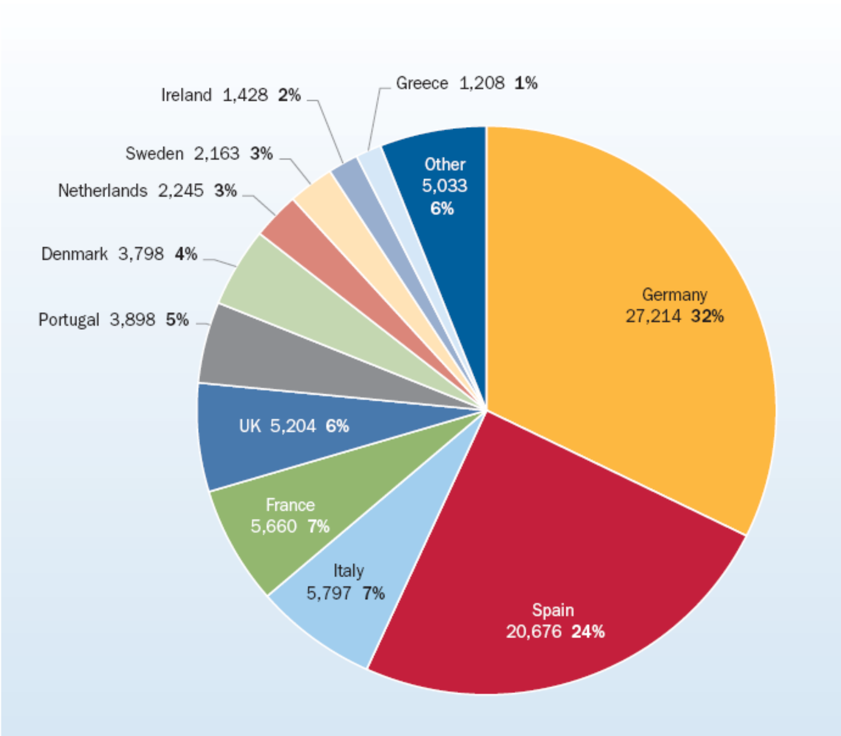


	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Rest of the world	0.3	0.3	0.8	0.2	0.6	2.1	1.4	2.7	2.4	5.3	7.7	11.3	18.3	28.3	28.9
EU	1.0	1.3	1.7	3.2	3.2	4.4	5.9	5.5	5.8	6.2	7.6	8.5	8.3	10.5	9.3
Total	**1.3**	**1.6**	**2.5**	**3.4**	**3.8**	**6.5**	**7.3**	**8.2**	**8.2**	**11.5**	**15.3**	**19.8**	**26.6**	**38.8**	**38.2**

Source: "Global wind report – annual market update 2010" – GWEC 2011; EWEA 2011

Figure 10 Global annual wind power capacity (1996 – 2010)

In Europe, Germany (27.2 GW) and Spain (20.7 GW) continue to be undisputed leaders in terms of total installed wind energy capacity (Figure 11). 57% of the EU's installed capacity is located in the two countries. By end 2010, five countries – Germany, Spain, Italy (5.8 GW), France (5.7 GW) and the UK (5.2 GW) – had passed 5 GW of total capacity (Figure 11) ([5.]).



Other	
Poland	1,107
Austria	1,011
Belgium	911
Romania	462
Bulgaria	375
Hungary	295
Czech Republic	215
Finland	197
Lithuania	154
Estonia	149
Cyprus	82
Luxembourg	42
Latvia	31
Slovakia	3
Malta	0
Slovenia	0

Figure 11 Member state wind power capacity (MW) and share (%) of total EU capacity at end 2010

During 2010, 9332 MW of wind power was installed in the European Union countries. This represents a decrease in the annual wind power installations of 10% compared to 2009. Of the 9332 MW installed in the EU, 883 MW were installed offshore. In 2010, the annual onshore market contracted by 15% compared to the previous year, whilst the offshore market grew by 51% compared to the previous year ([5.]).

Investment in EU wind farms in 2010 was €12.7 billion. The onshore wind power sector attracted €10.1 billion during 2010, whilst the offshore wind power sector accounted for around €2.6 billion.

In terms of annual installations, Spain was the largest market in 2010, installing 1516 MW, compared to Germany's 1493 MW. France was the only other country to install over 1 GW

(1086 MW), followed by the UK (962 MW) and Italy (948 MW). Sweden (604 MW), Romania (448 MW), Poland (382 MW), Portugal (363 MW) and Belgium (350 MW) (see Figure 12).

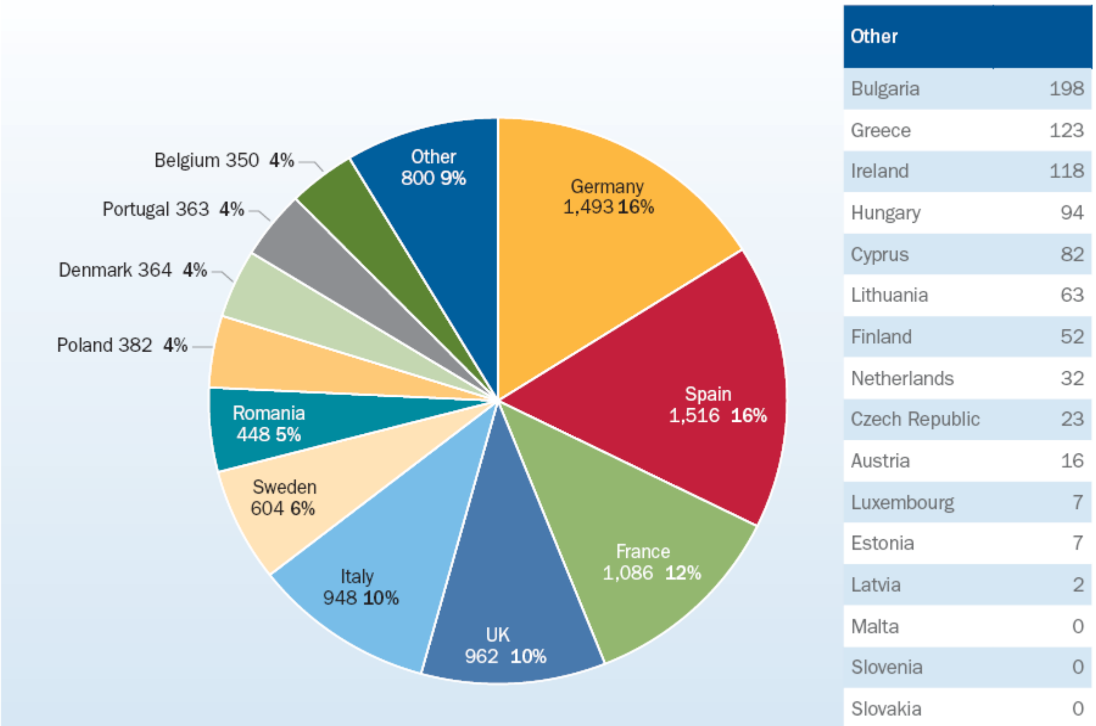


Figure 12 Member state market shares for new capacity in 2010 (total 9,332 MW)

Most EU Member States are now investing in wind power, partly as a result of the EU Renewable Electricity Directive passed in 2001 and its "successor", the EU Renewable Energy Directive passed in 2009 ([5.]).

Annual wind power installations in the EU have increased steadily over the past 3 years from 9.3 GW in 2010 to 11,159 GW in 2013 (Figure 13). Of the 11,159 MW installed in the EU, 9,592 MW were onshore and 1,567 MW offshore. In 2013, the onshore market decreased in the EU by 12%, whilst offshore installations grew by 34% (Figure 14). Overall, the wind energy market decreased by 8% compared to 2012 installations ([74.]).

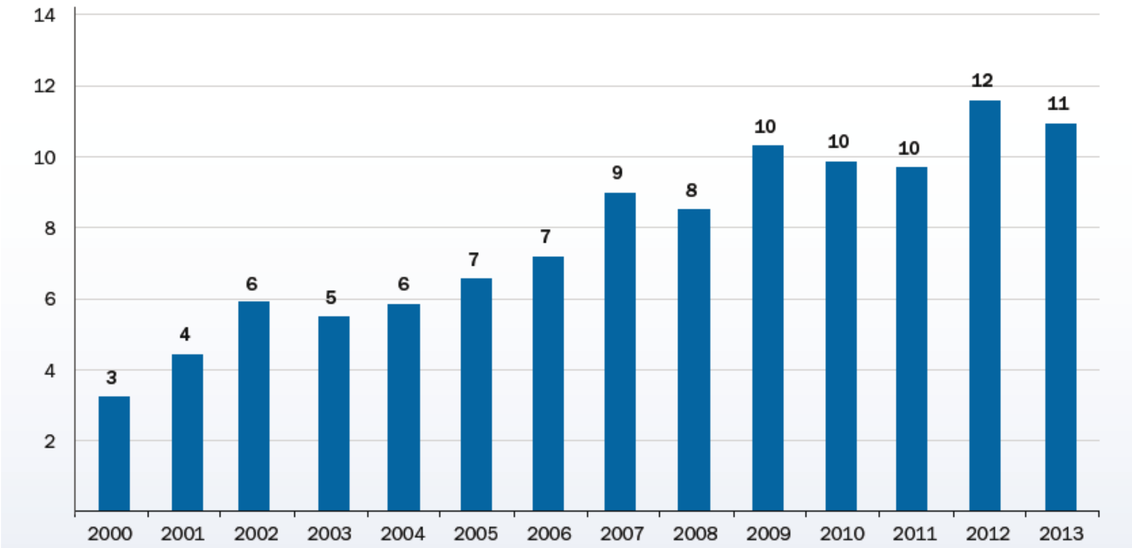


Figure 13 Annual wind power installations in EU (GW) – EWEA 2014

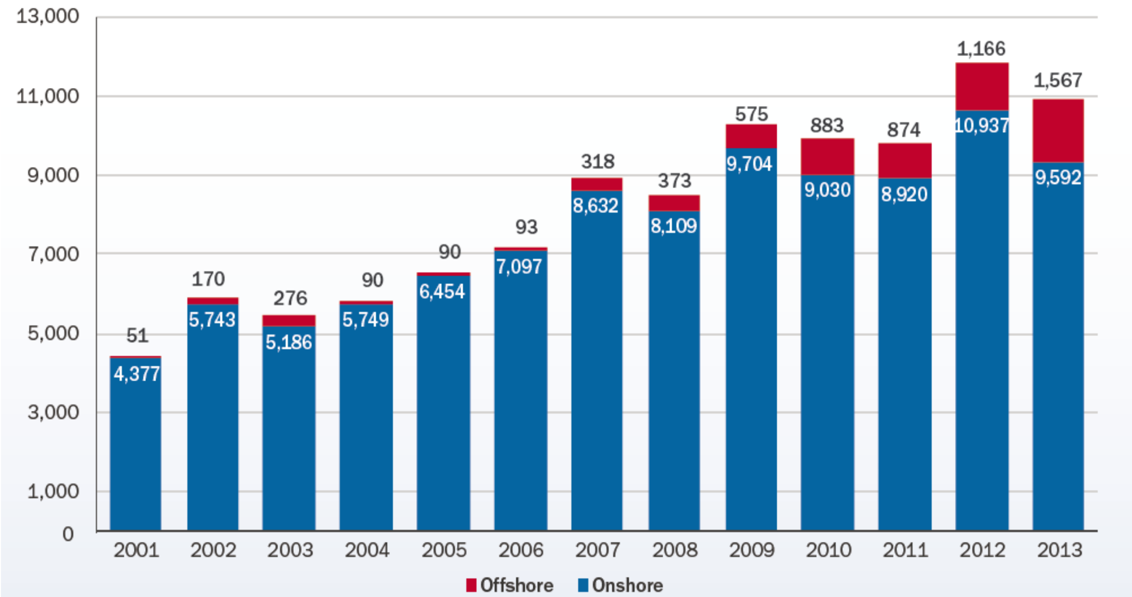


Figure 14 Annual onshore and offshore installations (MW) – EWEA 2014

In terms of annual installations, Germany was the largest market in 2013, installing 3,238 MW of new capacity, 240 MW of which (7%) offshore (Figure 15). The UK came in second with 1,883 MW, 733 MW of which (39%) offshore, followed by Poland with 894 MW, Sweden (724 MW), Romania (695 MW), Denmark (657 MW), France (631 MW) and Italy (444 MW).

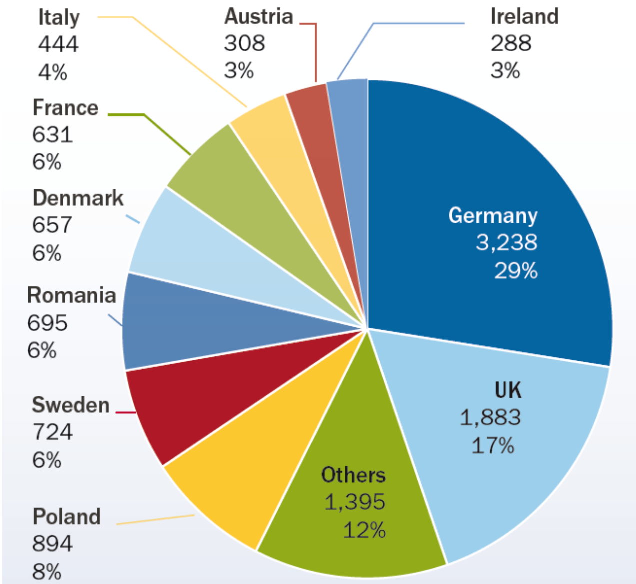


Figure 15 EU member state market shares for new capacity installed during 2013 in MW – EWEA 2014

The emerging markets of central and eastern Europe, including Croatia, installed 1,755 MW, 16% of total installations, 2% less than the previous year. Moreover, 46% of all new EU installations in 2013 were in just two countries (Germany and the Uk), a significant concentration compared to the trend of previous years when installations were increasingly spread across Europe. A number of previously large markets such as Spain, Italy and France have seen their rate of wind energy installations decrease significantly in 2013, by 84%, 65%, 24% respectively ([74.]).

Offshore accounted for almost 14% of total EU wind power installations in 2013, four percentage points more than in 2012, further confirming the high level of concentration in annual installations during 2013.

At end 2013, a total of 117 GW is installed in the European Union with a growth of 10% on the previous year and lower to the growth recorded in 2012 (+12% compared to 2011). Figure 16 shows the cumulative wind power installations in the EU at end 2013. Germany (34.3 GW) and Spain (23 GW) have the largest cumulative installed wind energy capacity in Europe and together they represent 49% of total EU capacity (Figure 17). The UK, Italy and France follow with, respectively, 10.5 GW, 8.6 GW and 8.3 GW. Amongst the newer Member

States, Poland, with 3.4 GW of cumulative capacity, is now in the top 10, in front of the Netherlands with 2.7 GW and Romania with 2.6 GW.

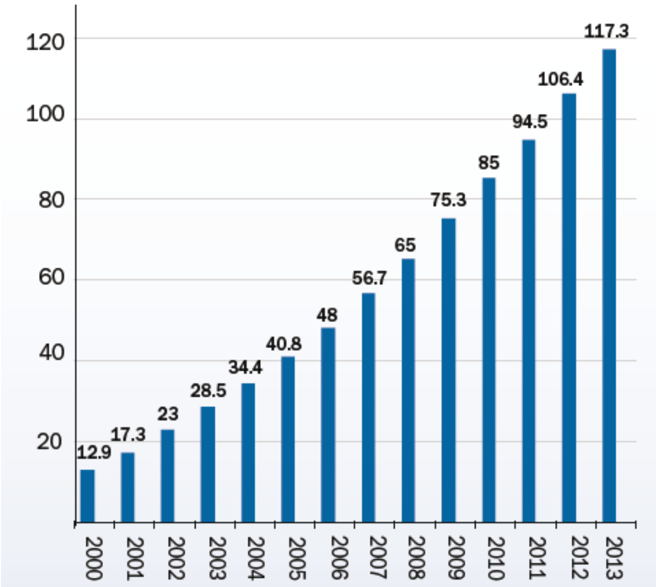


Figure 16 Cumulative wind power installations in the EU (GW) – EWEA 2014

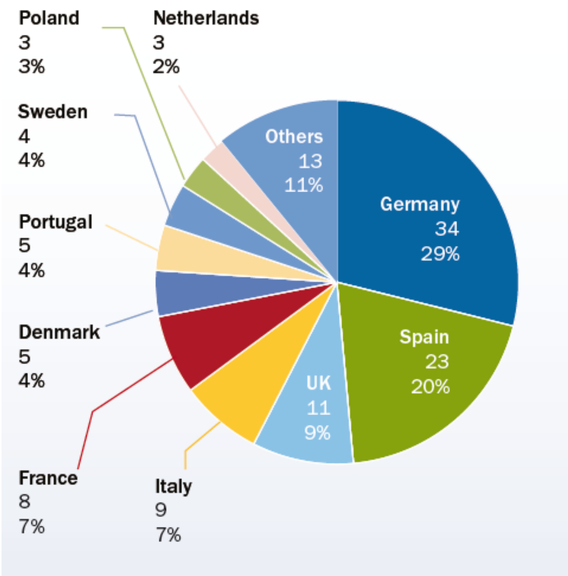
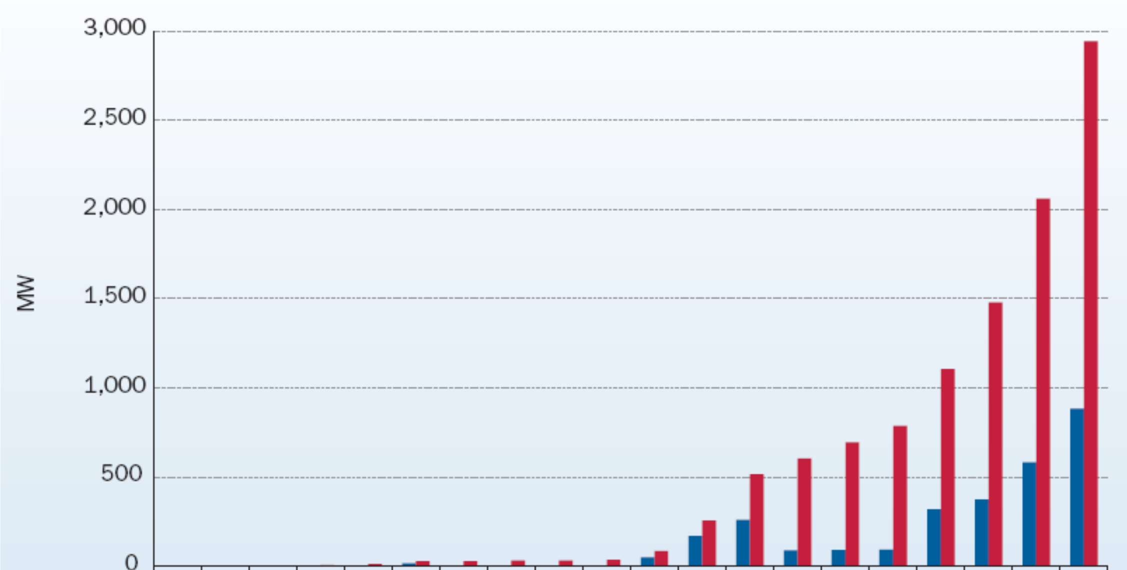


Figure 17 EU member state market shares for total installed capacity (GW) – EWEA 2014

2.1.2 The growth of offshore wind power in recent years (2010-2014)

With 2.9 GW installed at end 2010, offshore wind accounted for 3.5% of installed EU wind energy capacity (up from 2.7% in 2009) and 9.5% of new annual capacity. In 2010, 883 MW of offshore wind were installed, beating the previous year's record of 582 MW (Figure 18). Historically, the front-runner in offshore wind was Denmark. But by the end of 2010, with 458 MW of new offshore installations, the UK became the first country to total more than 1 GW of offshore capacity. In Europe, there are now eight EU Member States, and Norway, with installed offshore capacity (Figure 19) ([5.]).



	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Total annual	5	0	0	2	5	17	0	3	0	4	51	170	259	90	90	93	318	373	582	883
Total cumulative	5	5	5	7	12	29	29	32	32	36	86	256	515	605	695	787	1,106	1,479	2,061	2,944

Figure 18 Annual and cumulative installed EU offshore capacity 1991-2010 (MW)

	Installed in 2010	Total at end 2010
United Kingdom	458	1,341
Denmark	207	854
Netherlands	0	247
Belgium	165	195
Sweden	0	164
Germany	50	92
Finland	2	26
Ireland	0	25
Total EU	883	2,944
Norway	0	2.3
China	102	102
Total World	985	3,048

Figure 19 Offshore wind power (MW) in 2010

At end of 2011, a total of 1371 offshore turbines are installed and grid connected in European waters totalling 3812.6 MW spread across 53 wind farms in 10 countries.

The UK is by far the largest market with 2094 MW installed, representing over half of all installed offshore wind capacity in Europe. Denmark follows with 857 MW (23%), then the Netherlands (247 MW, 6%), Germany (200 MW, 5%), Belgium (195, 5%), Sweden (164, 4%), Finland (26 MW in near-shore projects) and Ireland 25 MW. Norway and Portugal both have a full-scale floating turbine of 2.3 MW and 2 MW respectively (Figure 20) ([6.]).

Finally, appendix A details the table of commissioned or financed and/or under construction offshore wind farms [23.].

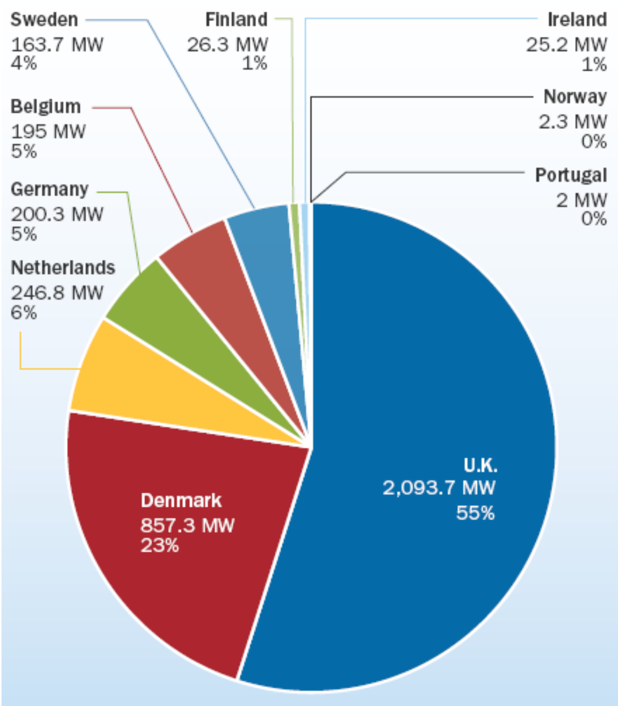


Figure 20 Installed capacity: cumulative share by country at end 2011 (MW)

At the end of 2012 there were 1,662 turbines totalling 5 GW of installed offshore wind capacity spread across 55 wind farms in 10 European countries (Figure 21). The produced energy is of 18 TWh, enough electricity to power almost five million households ([75.]).

In the last two years, the total installed capacity is increased of about 66%.

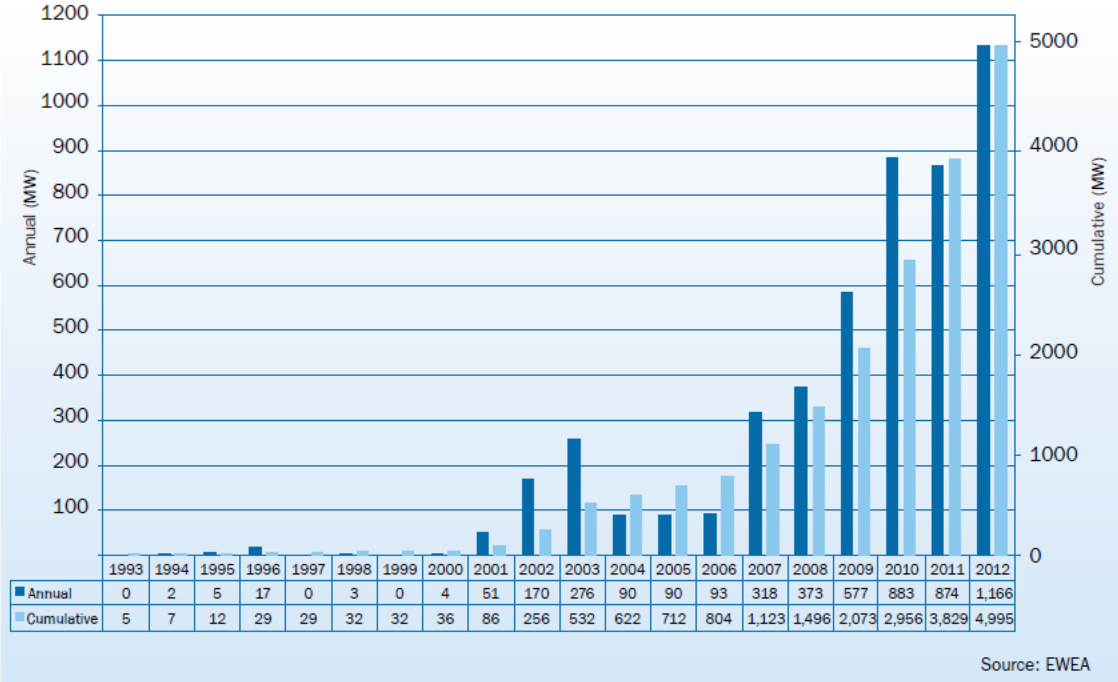


Figure 21 Annual and cumulative installations of offshore wind in Europe at end 2012 (MW)

Most of the offshore projects (3.2 GW or 65% of total capacity) are located in the North Sea. 16% of total capacity is located in the Baltic Sea and 19% in the Atlantic. There are currently no offshore wind farms in the Mediterranean, because the water is deep, and current commercial substructures are limited to 40m to 50m maximum depths. This restricts the potential to exploit offshore wind development in the Mediterranean ([75.]).

In Europe the grid connected offshore wind turbines rely on fixed foundations (Figure 22). The vast majority of those on monopile foundations, followed by gravity based substructures and space frame structures (tripod, jacket and tri-pile). Four experimental floating substructures in Europe are in a test phase: SeaTwirl, SWAY, Blue H and Poseidon.

The European offshore wind industry is increasingly developing offshore projects for water depths of over 50m to unlock the promising offshore market in the Atlantic, Mediterranean and deep North Sea waters. In many parts of Europe, off the coasts of Ireland, Portugal, Spain, Norway, UK, France and Italy, there are significantly larger offshore wind resources available in water deeper than 50m. Figure 23 shows the share of offshore wind resources in European countries, whereas the Figure 24 shows the map of available areas for floating platforms in Europe.

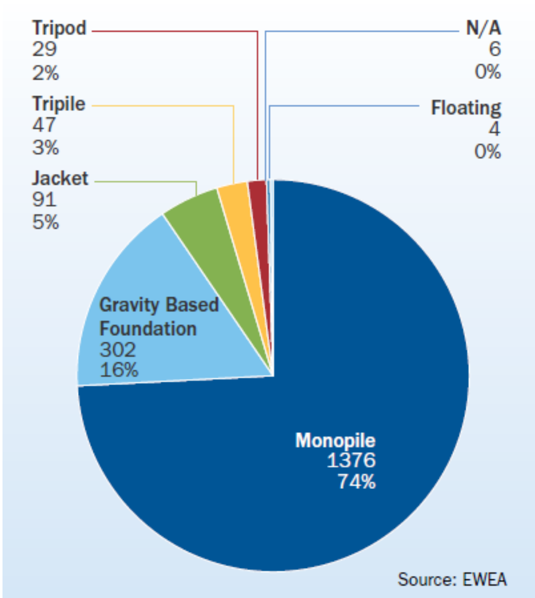


Figure 22 Share of substructure types for online wind farms, end 2012

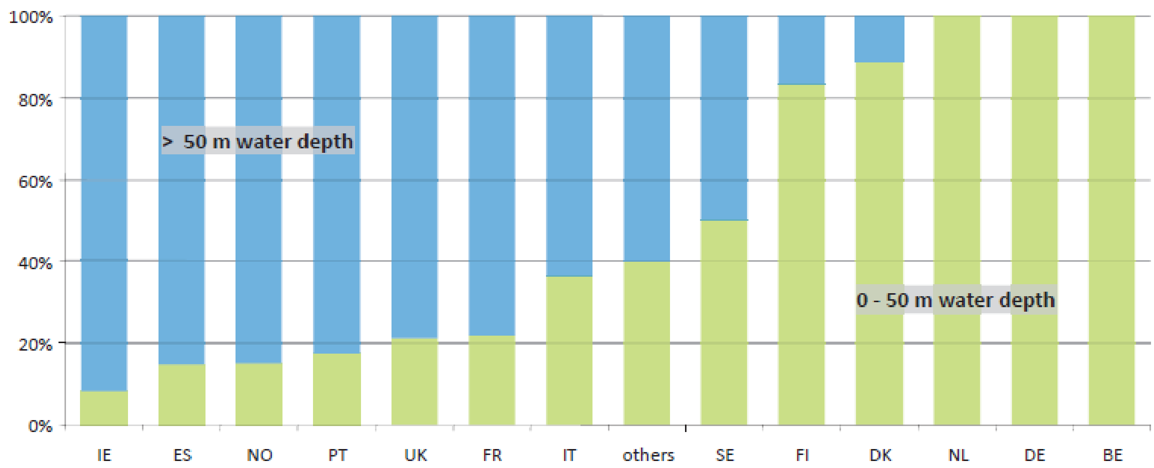


Figure 23 Share of offshore wind resources in European countries

EWEA has identified 40 deep water offshore projects either grid connected systems or under developement. More than 60% are located in Europe in 9 countries, 10% are in the US and 23% in Japan (see Figure 25).

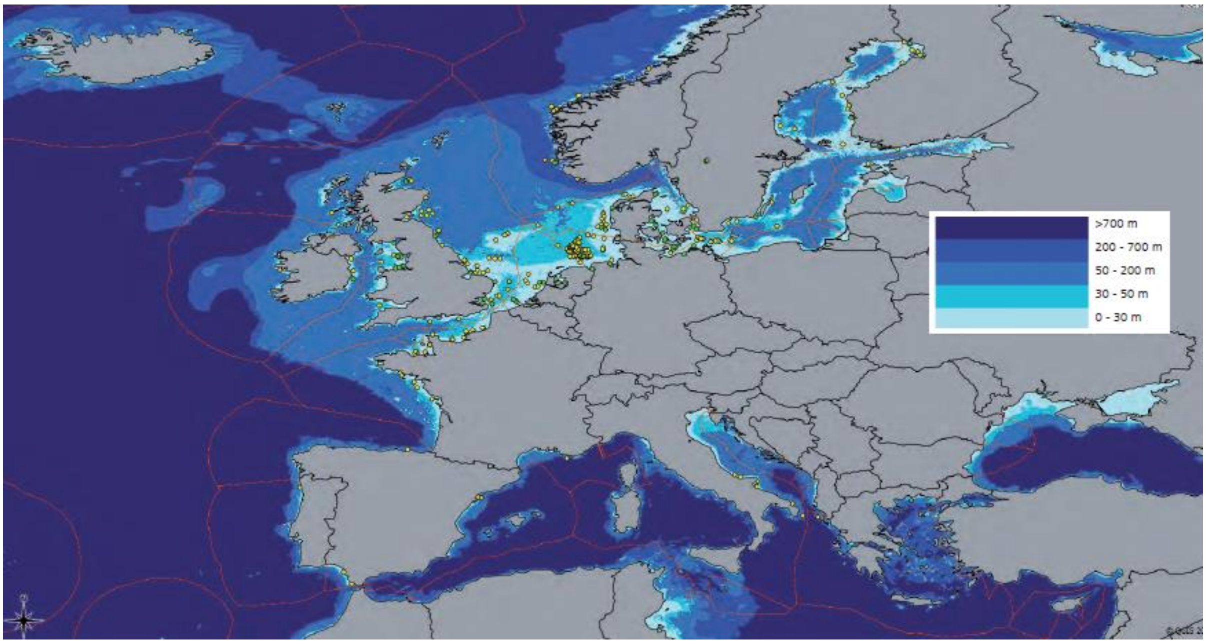


Figure 24 Available areas for floating platforms in Europe

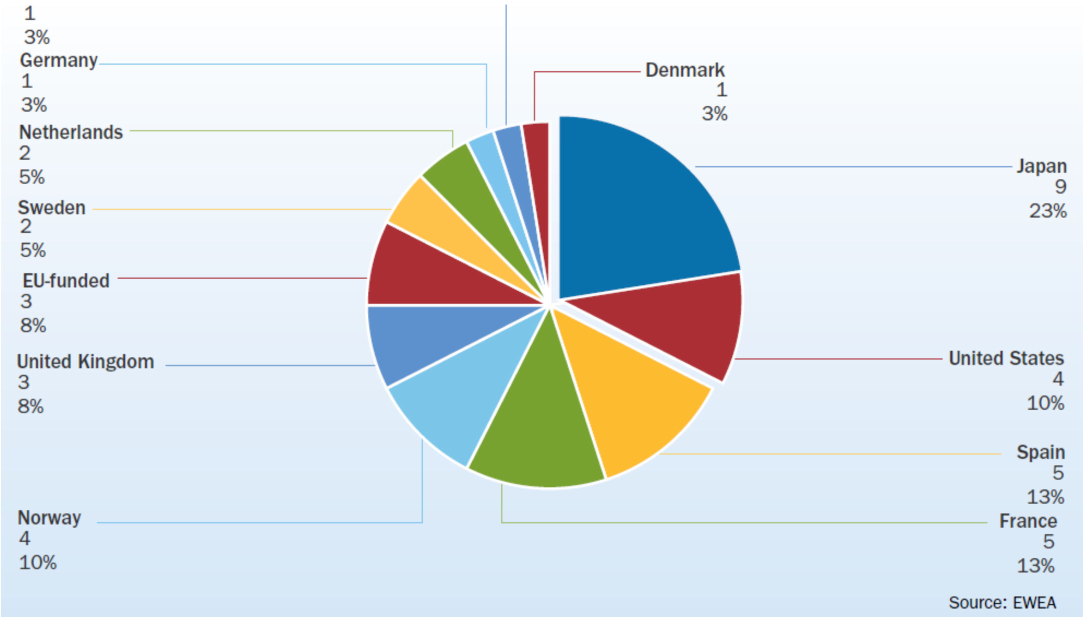


Figure 25 Location of deep water wind energy projetcs

The Table 1 outlines the deep offshore wind designs and projects developed in Europe, Japan and the US ([75.]).

Table 1 State of the art for deep offshore wind designs

No.	Project name	Company	Type of floater	Demo/Pilot		Prototype		Pre-Production/Serial		Origin
				Scale	Year	Turbine size (MW)	Date of deployment	Turbine size (MW)	Provisional date of deployment	
Grid connected systems										
1	Hywind	Statoil	Spar buoy			2.3 MW	2009-2012	3-7 MW	2016	Norway
2	WindFloat	Principle Power	Semi - submersible			2 MW	2011	5-7MW	2017	Portugal
3	DeepCWind Floating wind	Consortium made up of University of Maine, Advanced Structures and Composites Center (AEWC), Seawall, Maine Maritime Academy, Technip, National Renewable Energy Laboratory (NREL), MARIN, etc.	Design of one or more full scale floating wind turbine platforms	Scale models tested in tank	2011	Scale model (20kW) in near shore waters	2013	6 MW	2017	US
4	Kabashima Island, Kyushu	Ministry of Environment, Kyoto University, Fuji Heavy Industries, Toda Construction, National Maritime research Institute of Japan (turbine constructed by Japan Steel Works and Hitachi)	Spar	100 kW	2012	2 MW	2013			Japan
5	Hakata Bay Wind Lens, Kyushu	Kyushu University	Floater	2x3 kW	2011					Japan
Designs/Projects under development										
1	Advanced Floating Turbine	Nautica Windpower	Buoyant tower and downwind turbine				2012	5 MW	2014	US
2	Aero-generator X	Wind Power Ltd, Arup				10 MW	2013			UK
3	Azimut	Consortium of Spanish wind energy industry headed by Gamesa	Generating the know-how required to develop a large scale marine wind turbine			15 MW				Spain
4	Blue H TLP	Blue H	Submerged deepwater platform			5-7 MW	2015	5-7 MW	2016	Netherlands
5	Deepwind	EU project	Floating and rotating foundation plus vertical wind turbine			1 kW	2012	5 MW		Europe
6	Deepwater Innovative Wind Energy Technology (DIWET) Semisub	Pole Mer	Semi - submersible floater							France
7	Eolia Renovables de Inversiones (EOLIA)	Acciona Energy	SPAR, Tension leg platform (TLP) and semisubmersible	Tanks testing on 1:40 scale three floating wind turbine models	2011			5 MW		Spain
8	PelastarWave-Hub	The Glosten Associates	Floating platform system demonstrator			6 MW	2016			UK
9	IDEOL	IDEOL	Concrete floater	Tank test	2012	5-6 MW	2013	50 MW pre - series wind farm	2015	France
10	FLOTTEK	Consortium led by Gamesa, including Iberdrola	Tension leg turbine platform			2 MW				Spain
11	GICON TLP	GICON et al	Modular tension leg platform	1:25 Tank test	2013	2 MW	2014		2014	Germany
12	Floating Haliade	Alstom	Tension leg buoy (TLB) for water depths between 50m to 80m and TLP for water depths between 80m to 300m			6 MW				France
13	FLOATGEN	Gamesa, IDEOL, Stuttgart University, Acconia Windpower, Navantia, Olav Olsen, RSK Environment Ltd, Greenovate! Europe, Acciona Energy	Ring shaped surface floating platform Semi-submersible			2 MW and 3 MW	2015			Spain
14	Hexicon platform	Hexicon	Floater					54 MW wind and 15 MW wave	2014-2015	Sweden

No.	Project name	Company	Type of floater	Demo/Pilot Scale	Demo/Pilot Year	Prototype Turbine size (MW)	Prototype Date of deployment	Pre-Production/Serial Turbine size (MW)	Pre-Production/Serial Provisional date of deployment	Origin
15	HiPRwind	EU project							2016	Europe
16	Marina platform	EU project	Deepwater platforms that integrate (in a single infrastructure) a range of energy such as wind, wave, or sea currents						2014	Europe
17	Karmøy	SWAY	Spar buoy	1:6 down-scaled model	2011	2.3 MW		2.5-5 MW		Norway
18	Ocean Breeze	Xanthus Energy	Taut tethered buoyant	Tank Test	2011					UK
19	Pelagic Power	W2power	Hybrid wind and wave energy conversion plant					2x3.6 MW	2015	Norway
20	Poseidon Floating power	Floating Power	Semi - submersible			6 MW	2014			Denmark
21	Sea Twirl	Sea Twirl	Floating spar and vertical wind turbine	1:50 model						Sweden
22	Trifloater Semi-sub	Gusto	Semi - submersible					5 MW		Netherlands
23	Titan 200 Deep offshore platform	Offshore wind power systems of Texas	Self-installing floating platform							US
24	Vertiwind	Technip/Nenuphar/EDF EN	Semi - submersible			2 MW	2013	2 MW	2016	France
25	University of Maine	University of Maine, Renewegy	Semi-submersible tri-floater	20kW	2013					US
26	WindSea floater	Force Technology, NLI Innovation	Semi-submersible vessel with 3 corner columns	Tank test		3x1 MW		3x3.6 MW		Norway
27	WINFLO	Nass & Wind/DCNS	Semi - submersible			1 MW	2013	2.5 MW	2016	France
28	ZÈFIR test station	Catalonia institute for Energy Research, Gamesa, Alstom, Acciona	The development of a new, highly complex technology for deep water offshore wind turbines			20 MW bottom fixed and 50 MW (e.g 6-8) floating wind turbines	2013 bottom fixed, 2015-2016 floating		Test wind farm, not commercial	Spain
29	Fukushima Offshore Wind	Fukushima Offshore Wind Consortium (Mitsubishi, Hitachi, Marubeni Corporation, Tokyo University, Japan Marine United, Mitsui Engineering & Shipbuilding, Nippon Steel, Shimizu Corporation)	Semi-submersible			2MW	2013			Japan
30			Advanced spar			7MW	2014-2015			Japan
31			Semi-submersible			7MW	2014-2015			Japan
32	Shimizu Corporation	Shimizu Corporation, University of Tokyo, Tokyo Electric Power Company, Penta Ocean Construction	Semi - submersible						2017	Japan
33	Mitsui Zosen		Tension Leg Platform							Japan
34	National Maritime Research Institute of Japan		Spar							Japan
35	Hitachi Zosen	Hitachi Zosen, Toshiba	Semi- submersible			7.5 MW	2016			Japan

Source: Task Force EWEA

During 2013 in Europe 1,567 MW of new offshore wind power capacity were connected to the electricity grid, 34% more capacity than the previous year. 47% of all new capacity was installed in the UK (733 MW), less than in 2012 (73%). The second largest amount of installations were in Denmark (350 MW or 22%), followed by Germany (240 MW, 15%) and Belgium (192 MW, 12%), as showed in Figure 26.

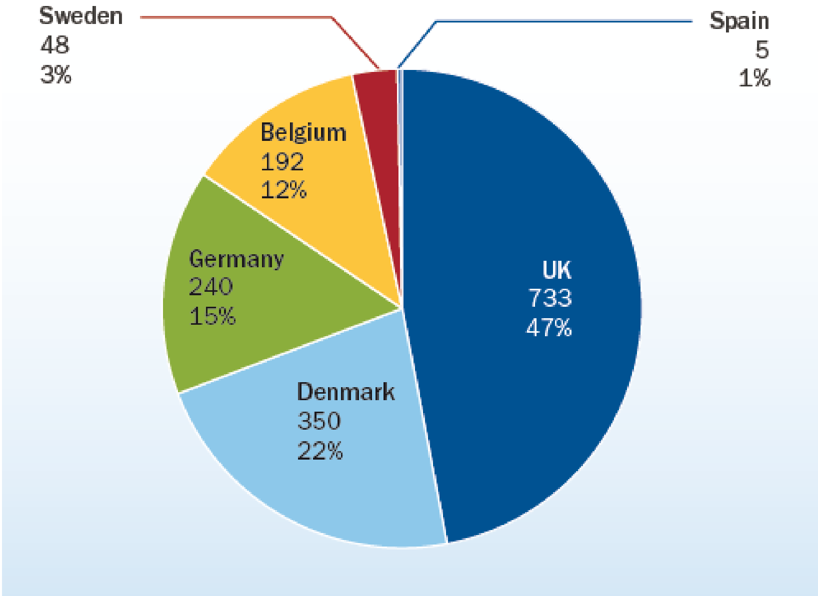


Figure 26 Share of annual offshore wind capacity installations per country during 2013 (MW) – EWEA 2014

Total installed capacity at the end of 2013 reached 6,562 MW (Figure 27), producing 24 TWh in a normal wind year, enough to cover 0.7% of the EU's total electricity consumption. The 6,562 MW of offshore wind capacity are mainly installed in the North Sea (4,363 MW, 66%), in the Baltic Sea (1,143 MW, 17%) and in the Atlantic Ocean (1,056 MW, 16%).

A total of 2,080 wind turbines are now installed and connected to the electricity grid in 69 offshore wind farms in 11 countries across Europe (Figure 28). The UK has the largest amount of installed offshore wind capacity in Europe (3,681 MW, 56% of all installations). Denmark follows with 1,271 MW (19%). With 571 MW (8.7% of total European installations), Belgium is third, followed by Germany (520 MW: 8%), the Netherlands (247 MW: 3.8%), Sweden (212 MW: 3.22%), Finland (26 MW: 0.4%), Ireland (25 MW), Norway (2.3 MW), Spain (5 MW) and Portugal (2 MW).

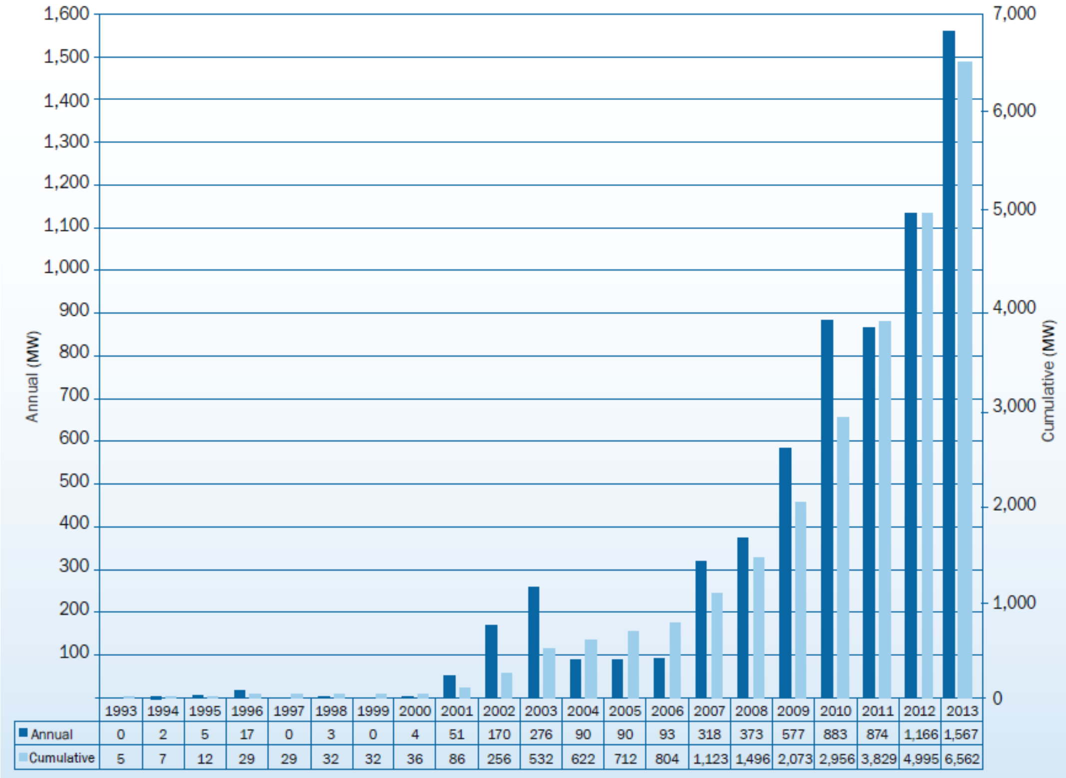
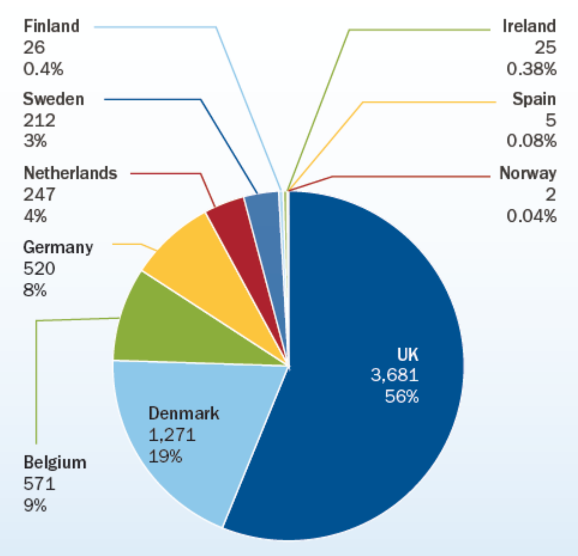


Figure 27 Cumulative and annual offshore wind installations (MW) – EWEA 2014

a) 

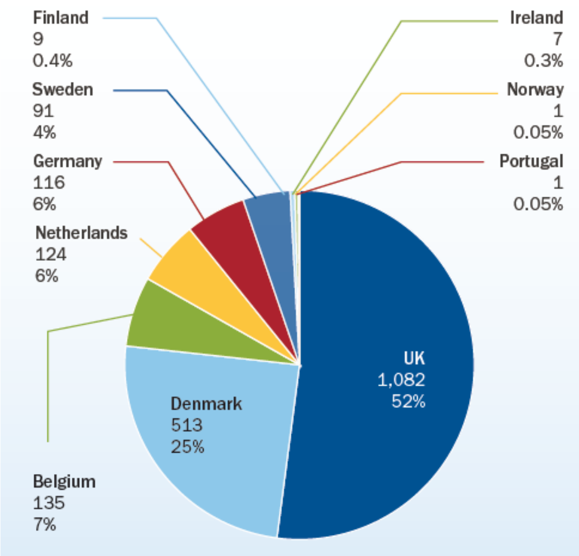
b) 

Figure 28 Cumulative share by country: installed capacity in MW (a) and installed wind turbines (b) – EWEA 2014

Siemens is the lead offshore wind turbine supplier in Europe with 60% of total installed capacity (Figure 29). Vestas (23%) is the second biggest turbine supplier, followed by Senvion (REpower) (8%), BARD (6%), WinWind and GE with respectively 0.8% and 0.5%. Other suppliers together make up just over 1% of the market ([76.]).

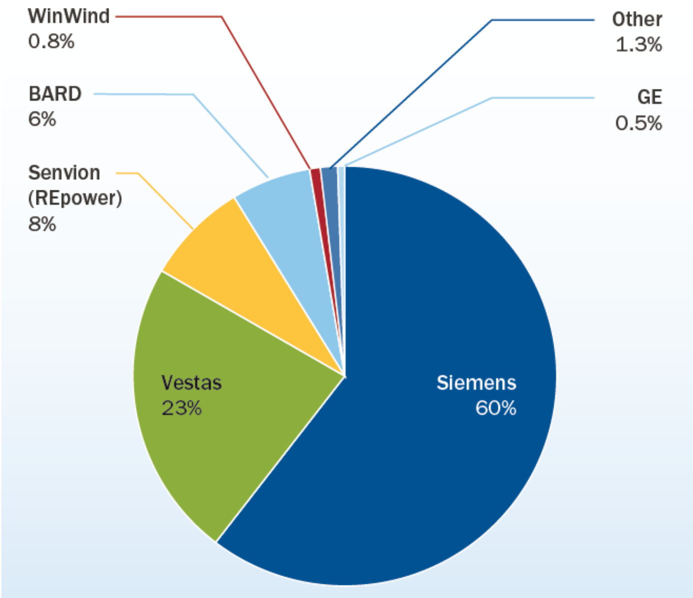


Figure 29 Wind turbine manufacturers share at the end of 2013 (MW) – EWEA 2014

At the end of 2013 there were 2,474 substructures fully installed at European offshore wind farms. The most common substructures used are monopiles (1,866 - 76% of all installed foundations). Gravity based foundations are the second most common with 303 units installed (12%), followed by jacket foundations (130 units: 5%), tripods (116 units: 5%) and tripiles (55 units: 2%). There are two experimental and two full scale floating substructures (Figure 30, [76.]).

With regard to the market outlook for 2015, with the completion of the wind farms that are currently under construction, some 3 GW of new capacity will come online; therefore the annual installations will remain stable in 2015. Moreover, EWEA has identified 22 GW of consented offshore wind farms in Europe and future plans for offshore wind farms totalling more than 133 GW (Figure 31).

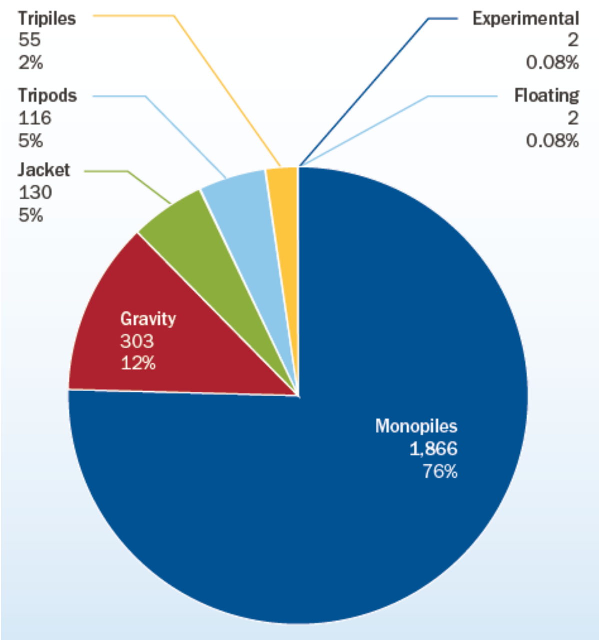


Figure 30 Share of substructure types for wind turbines – EWEA 2014

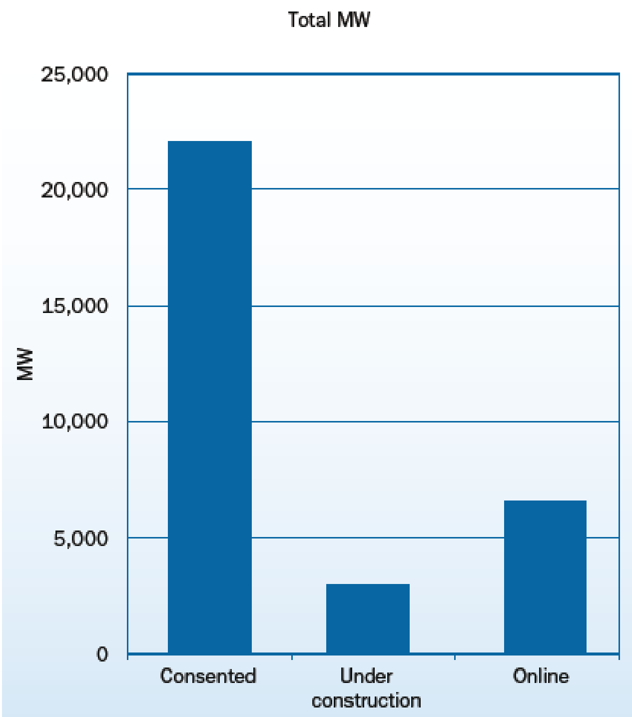


Figure 31 Offshore market: projects online, under construction and consented (MW) – EWEA 2014

In the medium term, an analysis of consented wind farms confirms that the North Sea will remain the main region for offshore deployment (68% of total consented capacity) with significant developments are also foreseen in the Baltic Sea (16% of consented capacity). The

Mediterranean could begin exploiting its offshore potential (6% of consented capacity), as showed in (Figure 32).

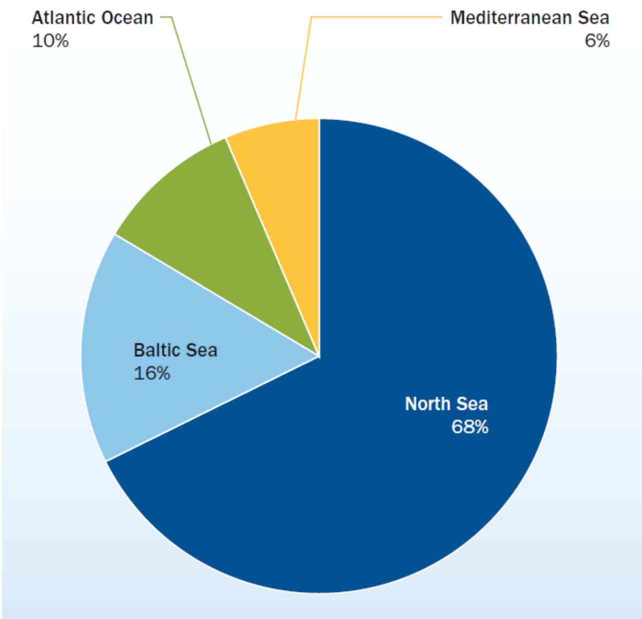


Figure 32 Share of consented offshore wind farms by sea basin– EWEA 2014

2.2 Offshore wind energy cost analysis

The offshore environment is certainly much more complex than the classic onshore site. First the staff has to travel by sea and this produces an increase in cost and time of construction. Moreover the higher risk of working at sea raises also the insurance cost.

Also the weather can have a heavy impact on the timing and costs of installation and maintenance, e.g. concerning with rough sea or storms. From the technological point of view, the sea is a very corrosive environment that requires more sophisticated and therefore more expensive applications. Foundations and supporting structures are a key aspect in offshore installations, where they require a greater amount of steel compared to onshore.

The Figure below shows a typical distribution of the investment costs of an offshore wind farm. The main items are turbine, foundation and the electrical transmission system ([7.][8.][9.]).

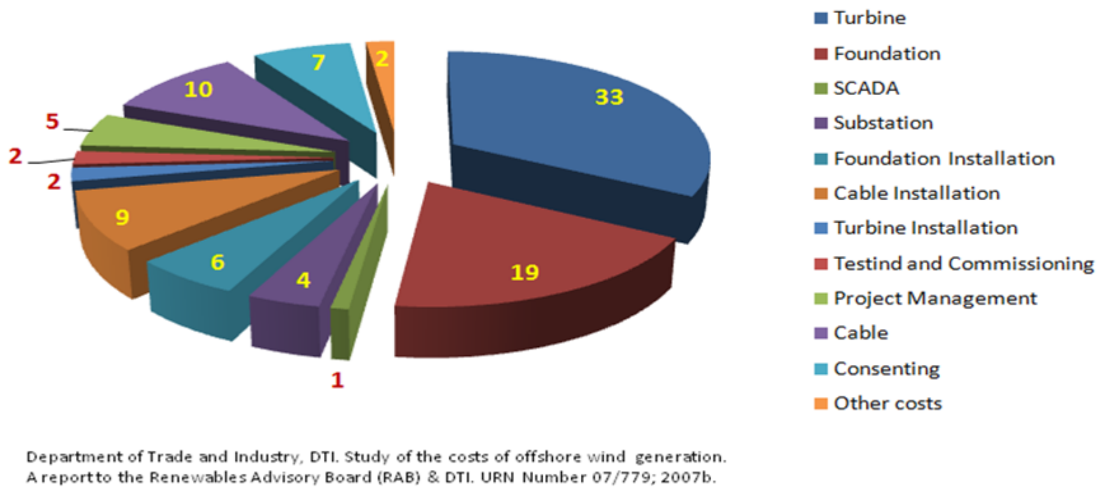


Figure 33 Distribution of investment costs of an offshore wind farm among its various components ([8.])

Costs of offshore wind farms are rather variable, depending on the plant characteristics:

- total capacity (Figure 34);
- size of the wind turbines (Figure 35);
- distance to shore (Figure 36);
- water depth (Figure 37)
- year of construction (Figure 38).

Obviously, increasing total capacity of the wind farm increases the investment cost (see Figure 34), however some costs are unlikely to scale linearly with the installed capacity, e.g. those costs concerning with installation, connection to the network or the same turbines that can be discounted compared to list price.

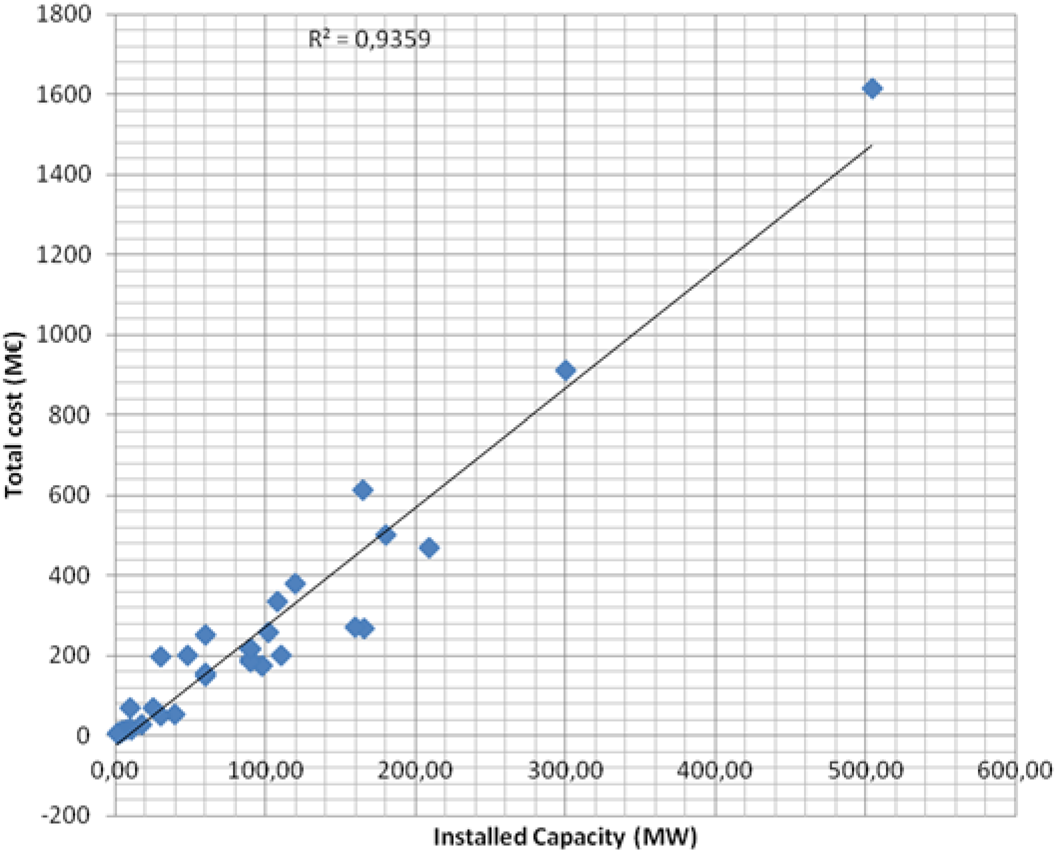


Figure 34 Total cost as a function of installed capacity for the wind farm. (Data of 36 wind farms)

With respect to the turbines size the scenary is more complex. The trend to use very large turbines produce two opposite effects: on one hand, for a given total power, less wind turbines mean also less support structures, hence a remarkable foundation saving; on the other hand such heavy structures need much larger ships to be installed, and so there is a very impressive increase in costs. Figure 35 shows as the cost of specific parks varies with the size of offshore turbines.

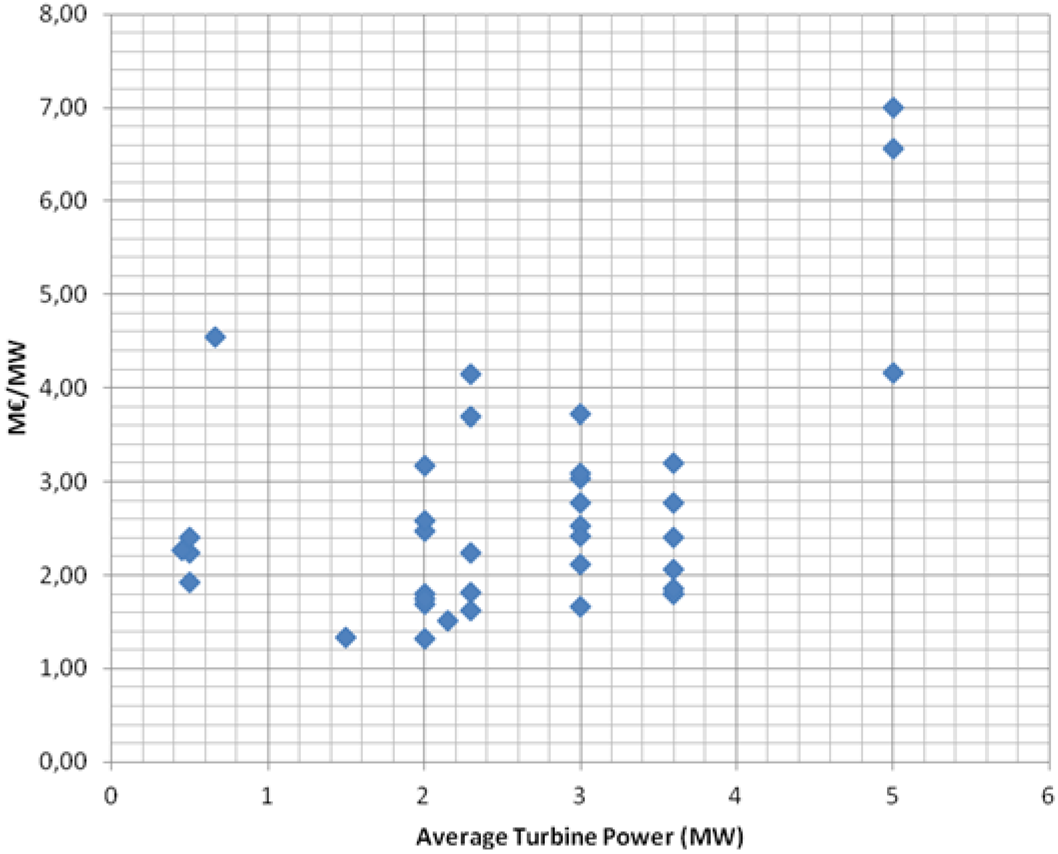


Figure 35 Cost of specific parks to vary the size of offshore turbines. (Data of 36 wind farms)

The distance to shore and the port facility influences both the construction phase and all phases of maintenance, indeed travels contribute significantly to the operational cost (see Figure 36). Obviously also costs of the necessary transmission cables depend on the distance to shore.

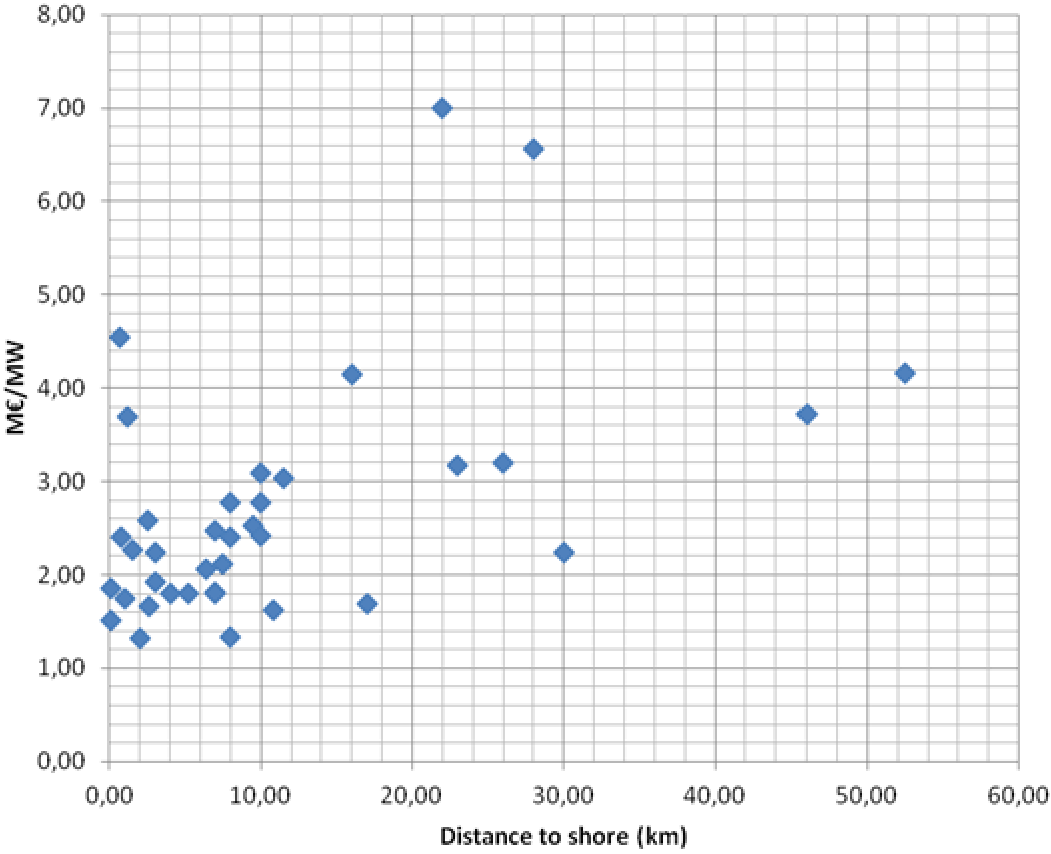


Figure 36 Specific costs of offshore wind farms as a function of distance to shore. (Data of 36 wind farms)

The water depth is another primary cost element. As in oil and gas facilities construction costs increase with depth (see Figure 37). At water depth greater than 25-30 m it is no longer feasible neither the gravity nor the monopile support structures that are the least expensive. Likewise, the laying of cables in deep water can be complex, in fact in some cases you can not use traditional boats but it can be necessary to make use of expensive remotely operated vehicles (ROV) and divers.

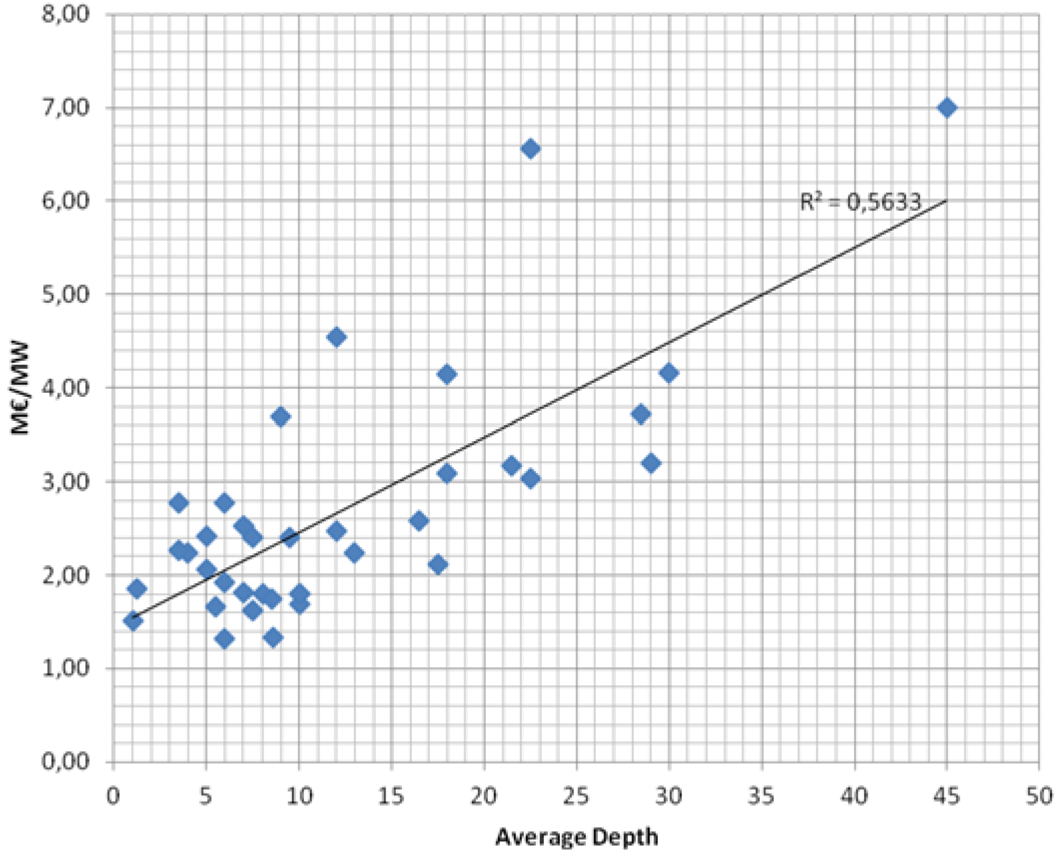


Figure 37 Specific costs of offshore wind farms as a function of average water depth. (Data of 36 wind farms)

Finally, the development technology is lowering its costs as it did previously for onshore applications, then the year of construction must be taken into account in any analysis of costs in order to compare the various wind farms (see Figure 38) ([4.][7.][9.]).

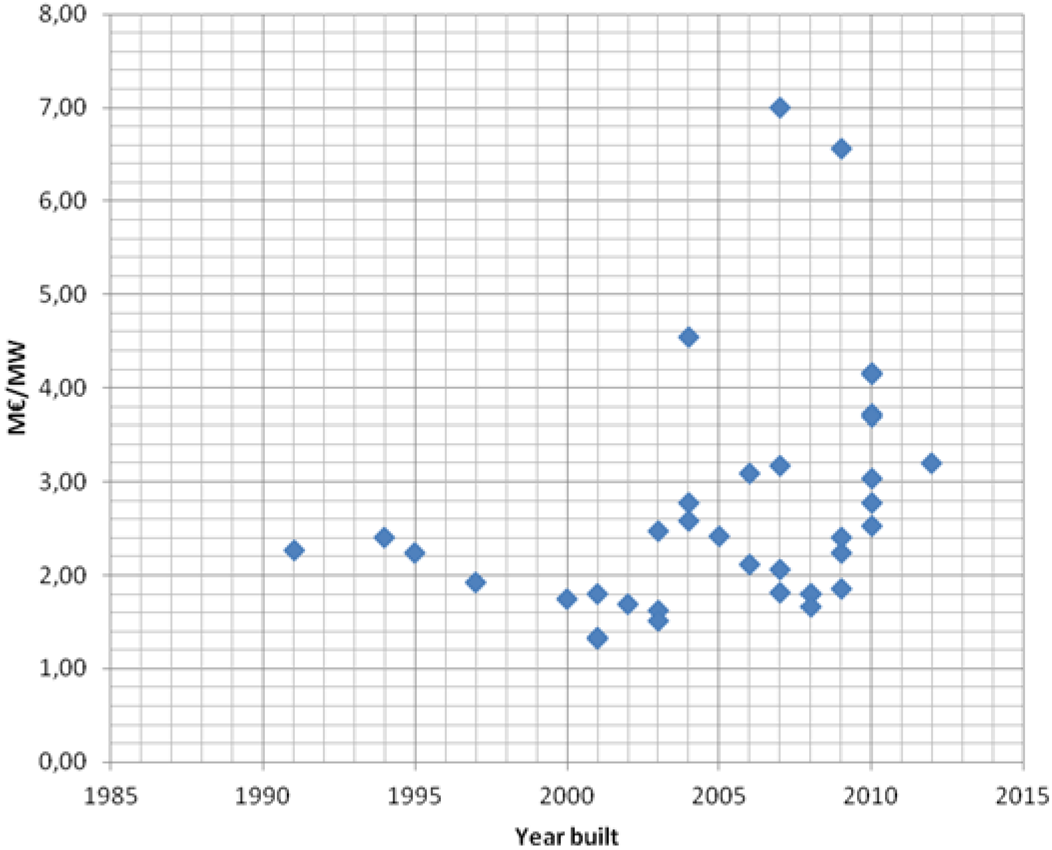


Figure 38 Specific cost of offshore wind farms over time (data of 36 wind farms).

With regard to the floating substructure, the costs mainly consist of the platform and the anchoring system. These costs are similar to those for fixed-bottom solutions installed in deep waters. The major difference between the two solutions is in the design and installation costs where floating offshore designs are expected to be cheaper.

Overall, floating offshore designs are also expected to produce more energy, as they can accommodate bigger turbines that lower the final cost per MWh.

The EWEA Offshore Wind Industry Working Group (OWIG) has evaluated deep offshore concept cost. It has taken account that most of the designs are still at an early stage of development and that some designs that include other types of power generation such as wave energy.

To evaluate the economics of floating designs, EWEA performed a comparison with jacket foundations, whose technical characteristics allow for installation in water depths of up to

45-50m. The findings show that floating offshore wind designs are competitive in terms of levelised cost of energy (LCOE) with existing jacket foundations from around 50m water depths. For a 100 MW wind farm, equipped with 5 MW turbines and installed in water depths of 100m, the capital expenditure (CAPEX) for floating designs is similar to the CAPEX of farms using jackets or tripod foundations at 50m water depths. Similarly the cost of energy produced by the floating designs would be competitive with the fixed-bottom foundations solution.

A study from GL Garrad Hassan showed that the LCOE of a 500 MW wind farm in water depths of 50m would be €128/kWh, lower than the current average levelised cost of fixed-bottom foundation wind farms in shallower waters ([79.]).

2.3 Wind Energy Production and Constructive Trends

2.3.1 Annual installation, wind energy production and investments (2011-2020)

Between 2011 and 2020, EWEA (European Wind Energy Association) expects the annual offshore market for wind turbines to grow steadily from 1.5 GW in 2011 to reach 6.9 GW in 2020 ([10.]). The total installed offshore wind capacity in 2020 will be 40 GW (see Figure 39). Including onshore, wind capacity in 2020 will be 230 GW.

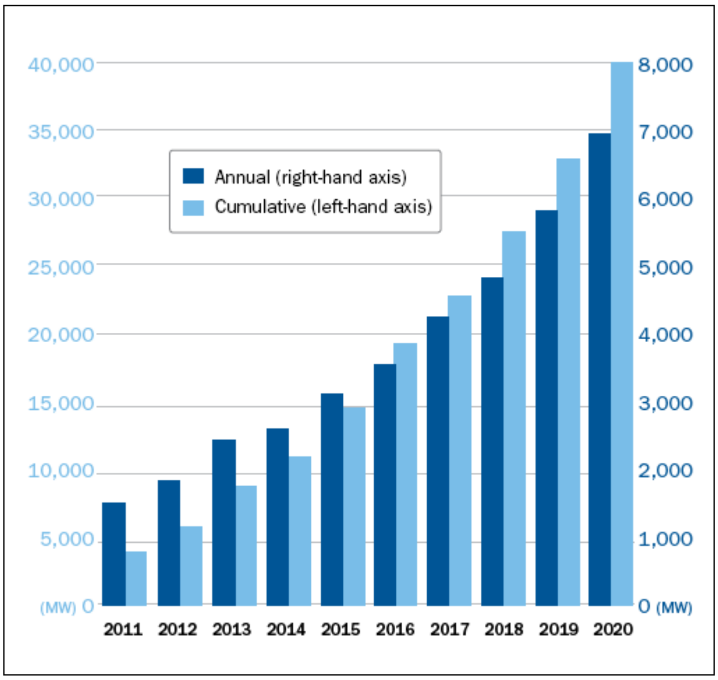
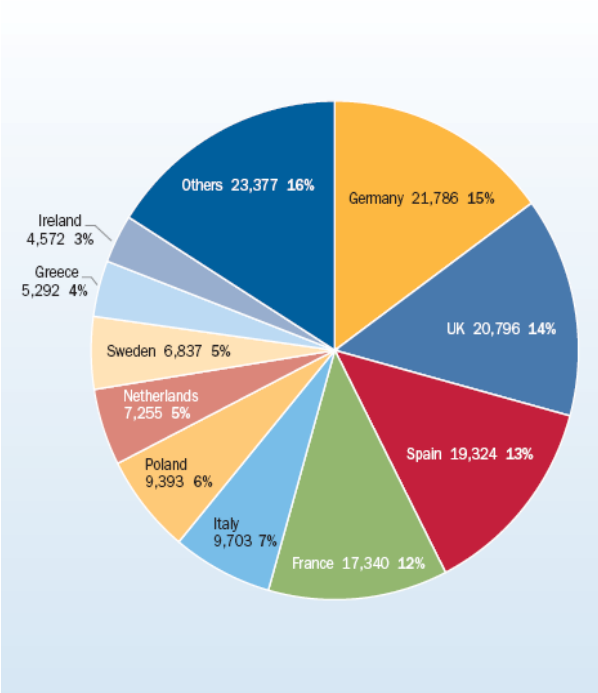


Figure 39 Offshore wind energy annual and cumulative installations 2011-2020 (MW)

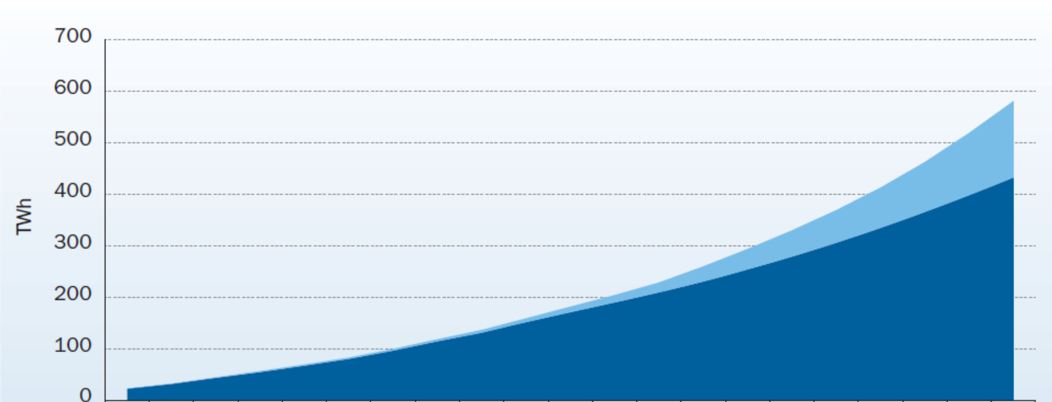
Figure 40 shows the national breakdown of the increase in wind power capacity according to EWEA's scenario. In total, wind energy capacity in the EU will increase of 146 GW by 2020, from 84.3 GW in 2010 to reach 230 GW in 2020. Germany will continue to be in the lead over the next 10 years, increasing its installed capacity of 21.8 GW. Spain, with a 19.3 GW increase would be overtaken by UK (adding 20.8 GW) and the France would come in fourth adding 17.3 GW. They are followed by Italy (9.7 GW), Poland (9.4 GW) and the Netherlands (7.3 GW) ([5.]).



Others	Increase in wind power capacity 2011-2020 (MW)	% of EU-27 increase in wind power capacity 2011-2020
Portugal	3,602	2.5%
Belgium	2,986	2.1%
Bulgaria	2,625	1.8%
Romania	2,538	1.7%
Austria	2,489	1.7%
Denmark	2,202	1.5%
Finland	1,703	1.2%
Czech Republic	1,385	1%
Lithuania	846	0.6%
Slovakia	797	0.5%
Hungary	605	0.4%
Slovenia	500	0.3%
Estonia	351	0.2%
Luxembourg	258	0.2%
Cyprus	218	0.1%
Latvia	169	0.1%
Malta	100	0.1%

Figure 40 Top 10 EU countries for increased wind power capacity in GW (2011-2020)

The 40 GW of offshore installed capacity in 2020 would produce 148 TWh of electricity in 2020, equal to between 3.6% and 4.3% of EU electricity consumption, depending on the development in electricity demand. Approximately a quarter of Europe's wind energy would be produced offshore in 2020 ([9.]). Including onshore, wind energy would produce 582 TWh, enough to meet between 14.3% and 16.9% of total EU electricity demand by 2020 (see Figure 41) ([5.]).



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Offshore	0.1	0.3	0.9	1.8	2.1	2.5	3.2	3.9	5.3	7.4	10.6	14.2	19.1	29.1	39.5	50.6	63.2	78.3	97.1	120.5	148.2
Onshore	22.5	31.7	43.5	54.8	67.3	80.3	96.4	114.5	131.2	151.6	171.1	190.0	209.5	230.8	254.2	279.2	305.9	334.7	365.6	398.8	432.7
Total	22.6	32.0	44.4	56.6	69.4	82.8	99.6	118.5	136.4	159.0	181.7	204.2	228.6	259.9	293.7	329.8	369.1	412.9	462.6	519.3	581.0

Figure 41 Wind energy production in the EU (2000 – 2020)

Annual investments in offshore wind power are expected to increase from €3.3 billion in 2011 to €8.81 billion in 2020 (Figure 42). In 2011, offshore wind power will avoid the emission of 10 Mt of CO_2, a figure that will rise to 85 Mt in the year 2020 ([10.]).

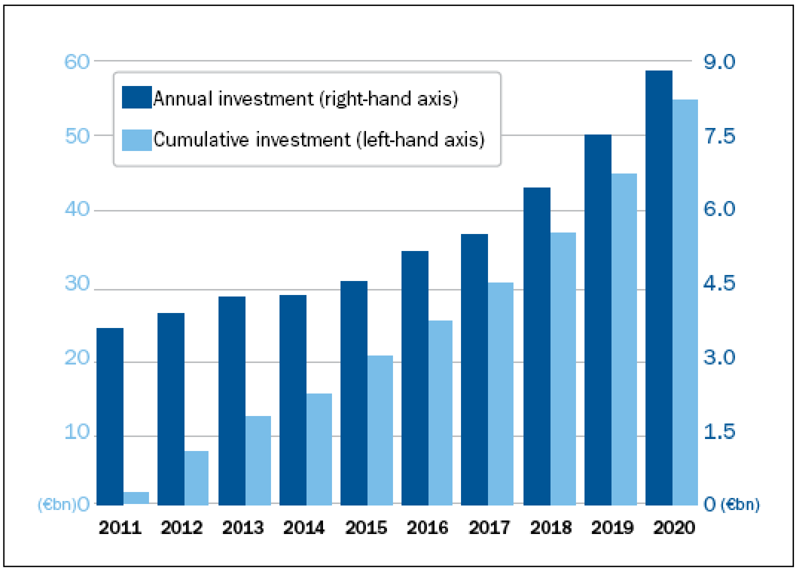


Figure 42 Annual and cumulative investments in offshore wind power 2011-2020 (€billion)

In 2013, investment in offshore wind farms ranged from €4.6 billion to €6.4 billion. A range is given as average project costs can vary significantly depending on size and location of the wind farms ([76.]). In Figure 43 are presented the annual investments in offshore wind farms in Europe since 2000, taking into account average installation costs per MW. 73% of the annual online capacity was financed by power producers. Developers have been active in financing (15% of the annual online capacity), followed by financial investors whose investments represent 12% of total capacity (Figure 44).

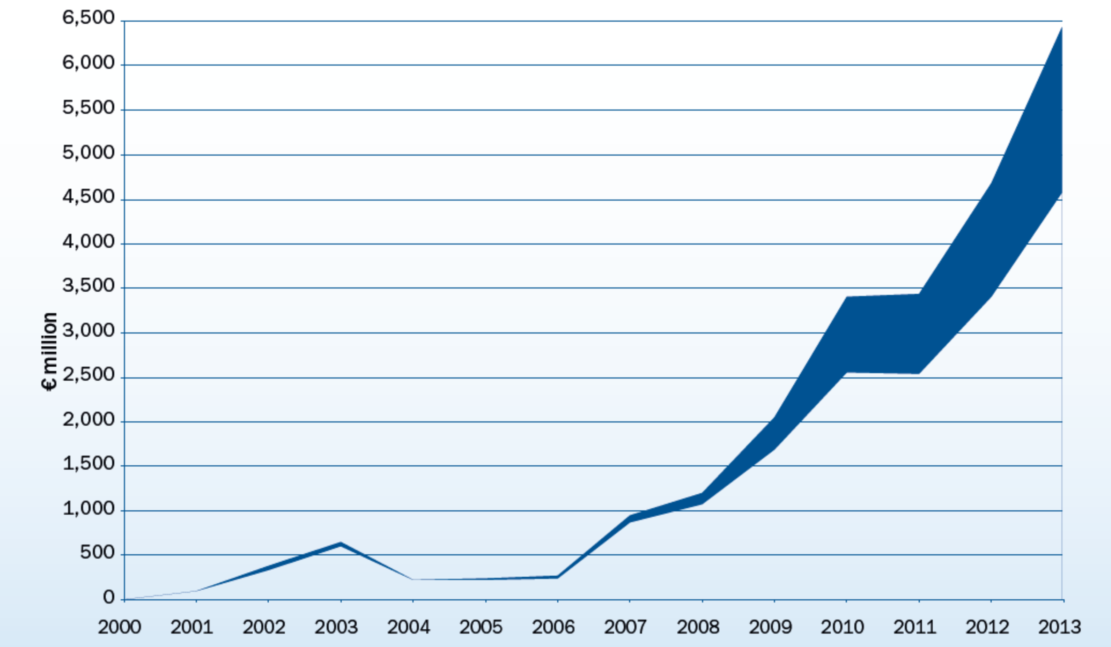


Figure 43 Annual investments in offshore wind farm at end 2013 – EWEA 2014

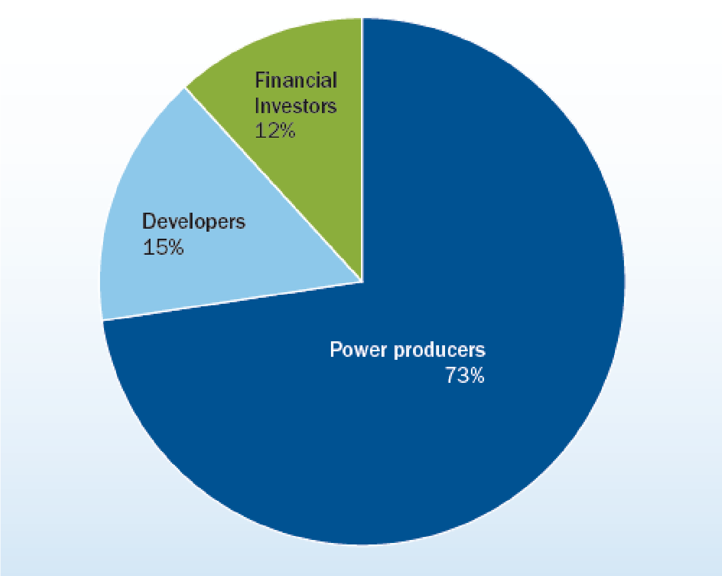


Figure 44 Investment in offshore wind farms by investor type at end 2013 – EWEA 2014

2.3.2 Annual installation, wind energy production and investments (2021-2030)

By 2030, EWEA expects 400 GW of wind energy capacity to be operating in the EU – 250 GW on land and 150 GW offshore.

Between 2021 and 2030, the annual offshore market for wind turbines will grow steadily from 7.7 GW in 2021 to reach 13.6 GW in 2030 (Figure 45). Given its larger potential, it can be expected that total offshore wind capacity will exceed onshore capacity at some point beyond 2030 ([10.]).

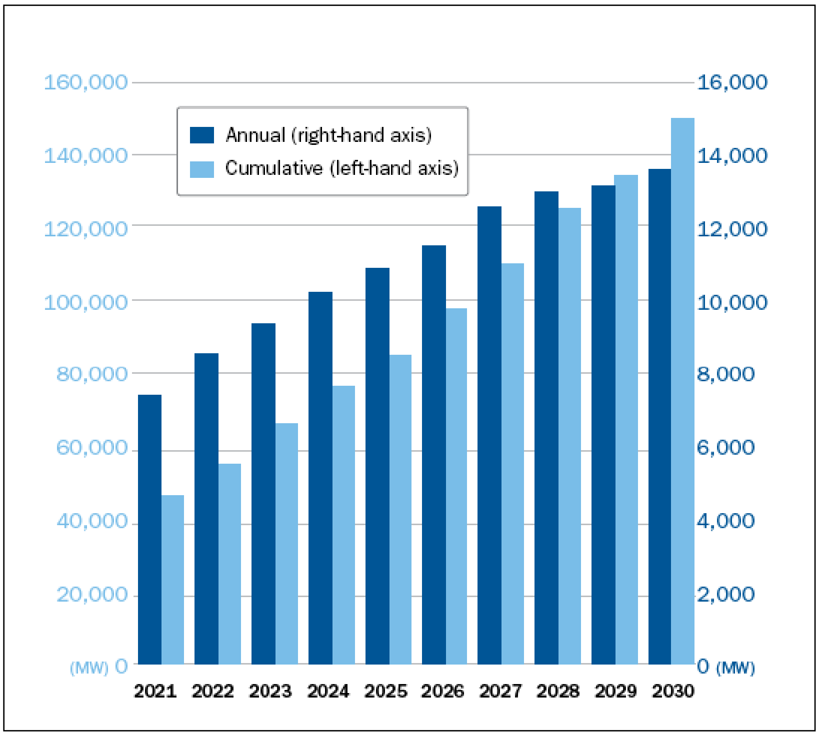
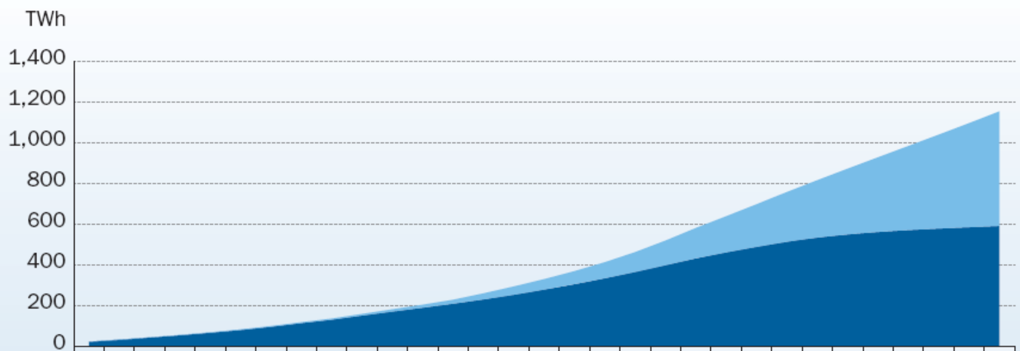


Figure 45 Offshore wind energy annual and cumulative installations 2021-2030 (MW)

By 2030, wind power in the EU will produce 1,154 TWh – 591.3 TWh onshore and 562.4 TWh offshore (Figure 46), meeting 28.5% of EU electricity demand, according to EWEA's calculations. Approximately half of Europe's wind electricity would be produced offshore in 2030. Due to the higher capacity factor of offshore turbines, the 150 GW offshore wind capacity will produce almost as much power as the 250 GW of onshore capacity in 2030.

Figure 46 show as the onshore development forms a classic S-curve of early exponential growth being replaced by saturation towards 2030 ([5.]).



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Offshore	0	0	1	2	2	2	3	4	5	7	11	14	19	29	40
Onshore	22	32	44	55	67	80	96	115	131	152	171	190	209	231	254
Total	23	32	44	57	69	83	100	118	136	159	182	204	229	260	294

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Offshore	51	63	78	97	120	148	177	209	244	281	322	366	412	461	511	562
Onshore	279	306	335	366	399	433	462	489	514	534	550	562	571	579	586	591
Total	330	369	413	463	519	581	639	698	757	816	873	928	983	1,040	1,096	1,154

Source: EWEA 2011

Figure 46 Electricity production from onshore and offshore wind in the EU (2000-2030)

Annual investments in offshore wind power are expected to increase from €9.8 billion in 2021 to €16.5 billion in 2030 (Figure 47). In 2021, offshore wind power will avoid the emission of 100 Mt of $C0_2$, a figure that will rise to 292 Mt in the year 2030 ([10.]).

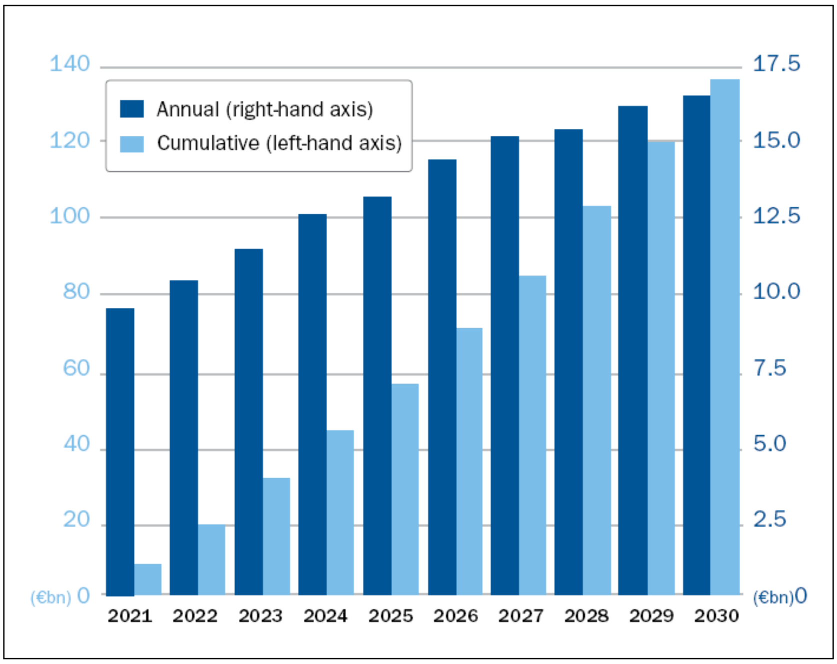


Figure 47 Annual and cumulative investments in offshore wind power 2021-2030 (€billion)

2.3.3 Offshore future trends

As technology develops and experience is gained, the offshore wind industry will move into deeper water and further from the shore. Looking at the wind farms proposed by project developers, the wind industry will gradually move beyond the so-called 20:20 envelope (20m water depth, 20 km from shore) ([10.]). The following scatter graph shows the probable future development trends of the offshore industry in the 2025 timeframe (approximately).

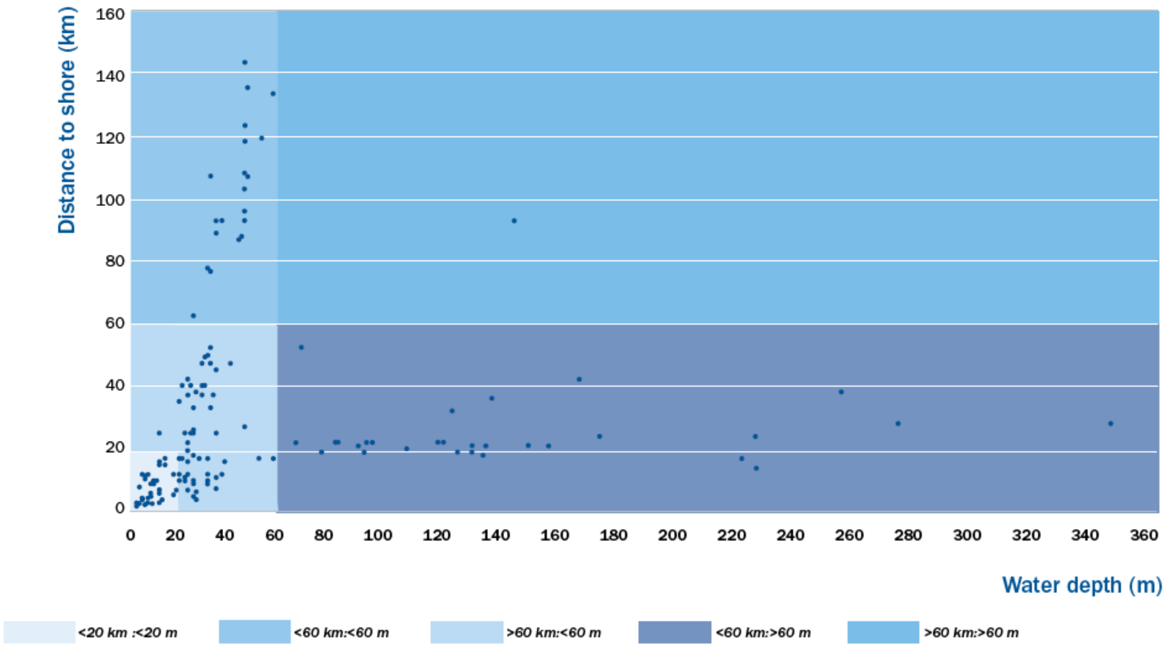


Figure 48 Wind farms proposed in terms of water depth (m) and distance to shore (km)

Identified trends:

- **<20 km:<20m**

At the moment operating wind farms tend to be built not further than 20km from the shore in water depths of not more than 20m.

- **<60 km:<60m**

The current 20:20 envelope will be extended by the majority of offshore farms to not more than 60 km from shore in water depths of not more than 60m.

- **>60 km:<60m**

Far offshore development, characterized by farms far from shore (more than 60 km) connecting in ideal situations to offshore super nodes, with a water depth generally between 20m and 60m.

- **<60 km:>60m**

Deep offshore – based on project proposals highlighted to EWEA from project developers using floating platform technologies during the course of the next decade, not further than 60 km from shore.

- **>60 km:>60m**

Deep far offshore – this scatter graph highlights the future long term potential of combining an offshore grid (far offshore) with floating concepts (deep offshore).

At the end of 2013, the average water depth of online wind farms was 16 m and the average distance to shore 29 km ([76.]). Looking at projects under construction, consented or planned, average water depths and distances to shore will likely increase (Figure 49).

With regard to the average size of offshore wind farm, in 2012 the average size of offshore wind was 286 MW while in 2013 it was 482 MW, 68% more than the previous year (Figure 50, [76.]).

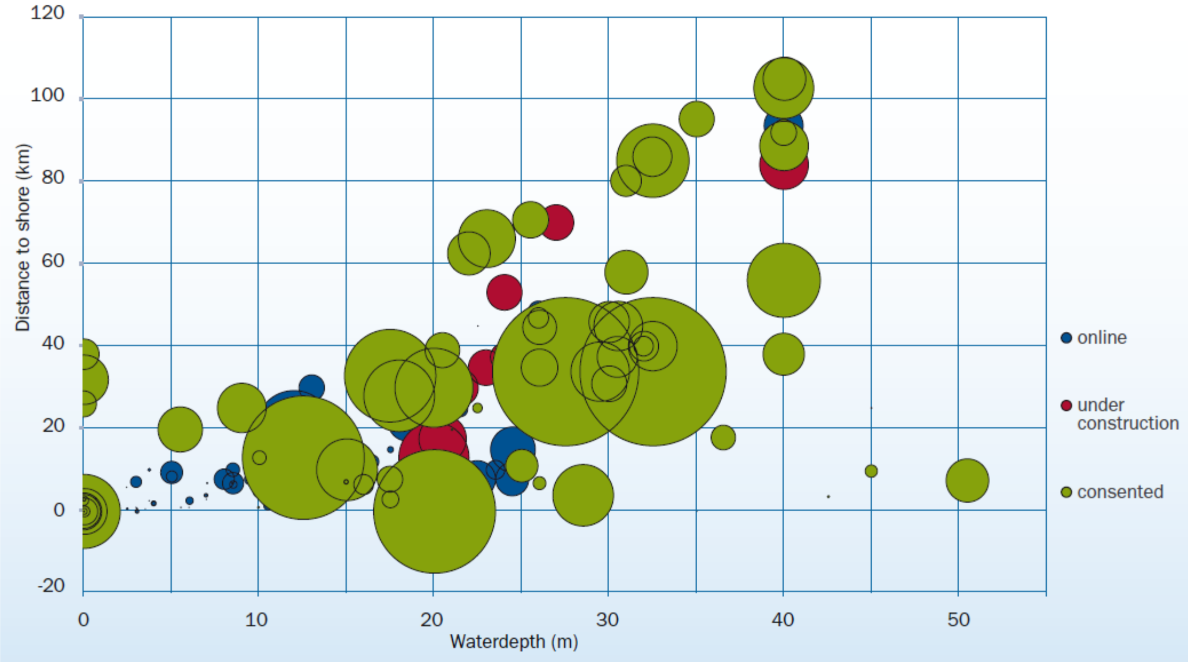


Figure 49 Average water depth and distance to shore of online, under construction and consented wind farms – EWEA 2014

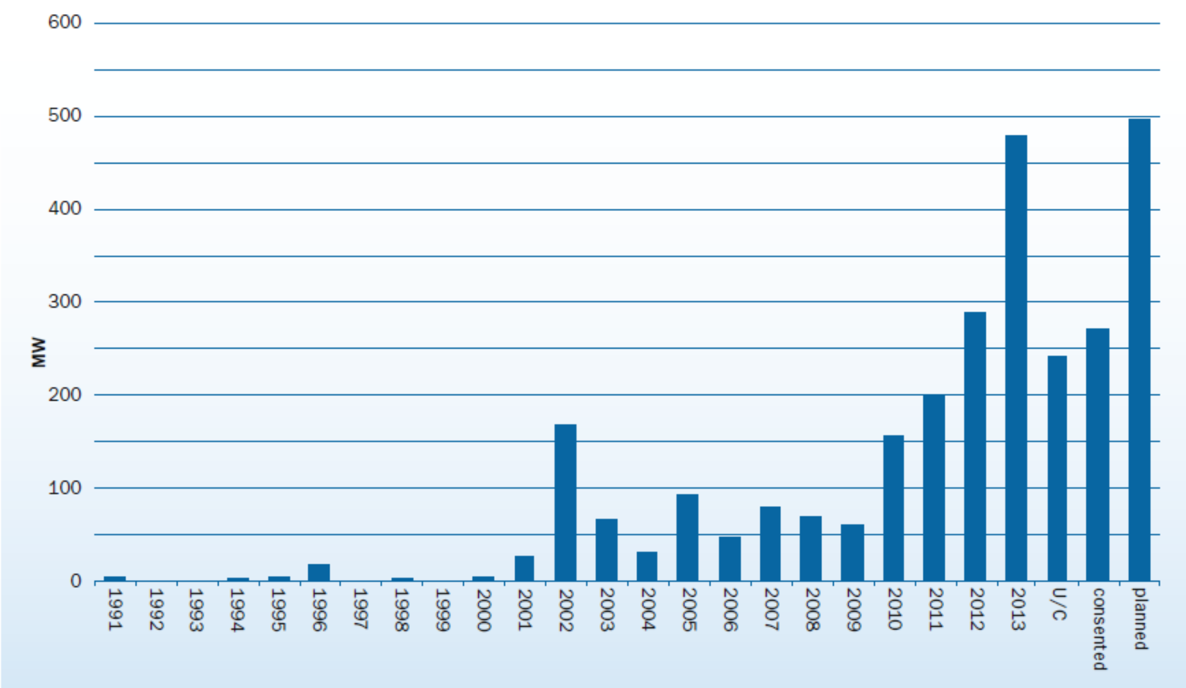


Figure 50 Average size of offshore wind farm projects – EWEA 2014

2.3.4 Turbine size evolution

A wind power system is a sophisticated combination of components and sub-systems that have to be designed in an interdisciplinary and integrated manner. In addition, the size and complexity of wind turbines is increasing rapidly over time (see Figure 51) ([3.]).

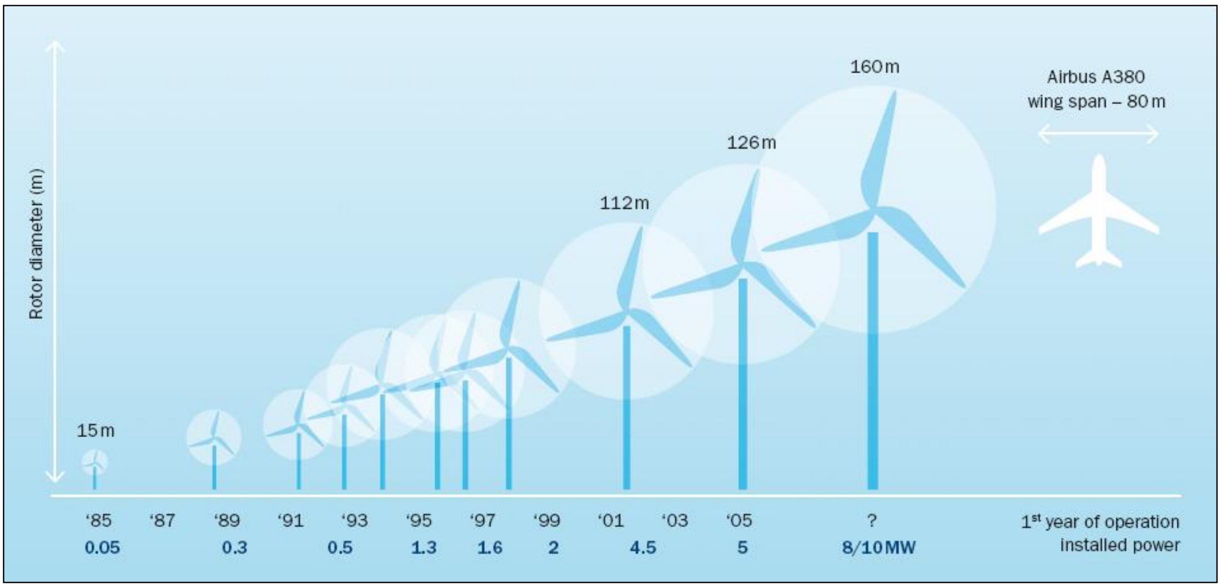


Figure 51 Size evolution of wind turbines over time

Horizontal-axis wind turbines (HAWT), designed for offshore power systems, are substantially assimilated to onshore wind turbines. In offshore installations the turbines have on average larger size, in order to have a lesser incidence of the cost of marine foundation and a greater annual energy production. The operating wind farm with the biggest turbines is the BARD1 wind farm where there are installed 80 turbines each with a rated capacity of 5 MW and a rotor diameter of 122 m. After all in offshore installations there are not problems of impact on the environment, so large sizes are possible.

The main difference between offshore and onshore is the support structure, with respect to the technological specificity of the marine foundation. This is fundamental for a preliminary evaluation of the seabed. Another different element, compared to onshore sites, is the wind velocity that is higher and more constant (so more predictable) and is associated with a lower turbulence. This favorable wind condition allows offshore wind turbines to produce more electrical energy than onshore ones with the same rated power (the Capacity Factor is higher offshore). However a more intense state of stress is created on the turbines. In fact off-shore there are extreme environmental conditions, because of waves, strong storms and brackish water (illustrated in Figure 52), which force wind turbines constructors to raise the necessary structural requirements, in particular concerning with the innovative floating turbines designed for large water depths ([3.] [11.]).

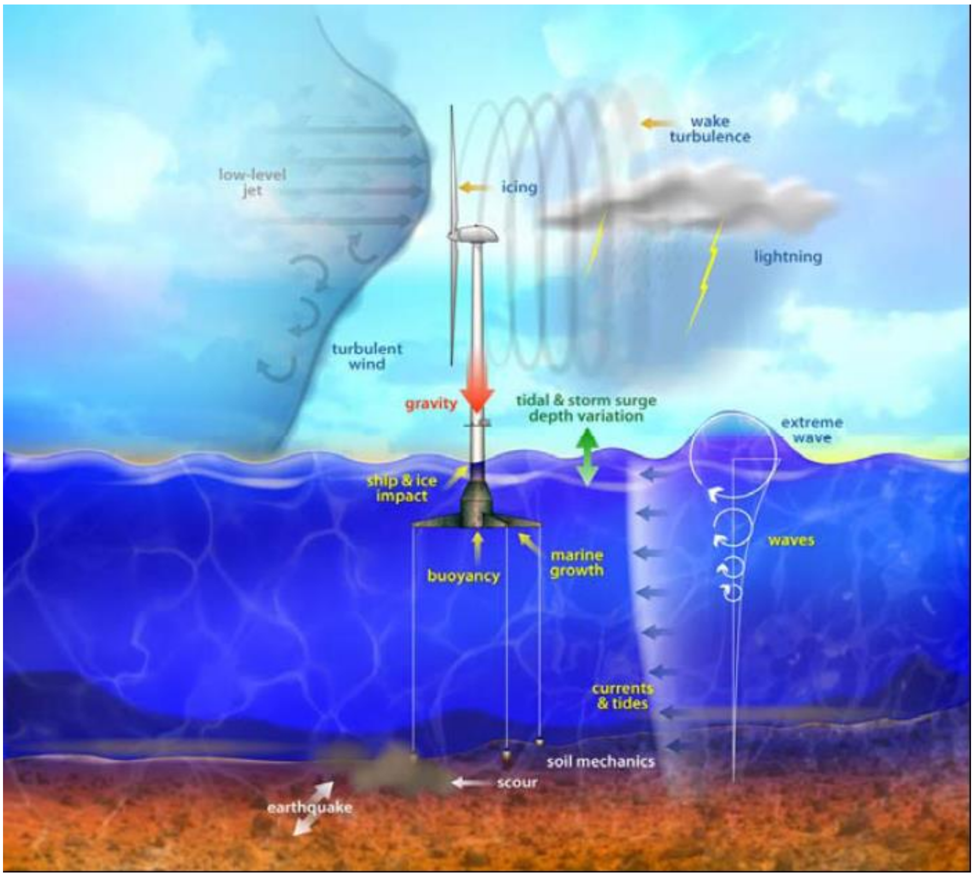


Figure 52 Representation of the extreme environmental conditions for a offshore wind turbine (in this case a floating turbine)

In addition the difficulty to get to turbines, strongly influenced by the climatic conditions, forces wind turbines to have a higher level of realiability in order to contain the maintenance costs. In offshore turbines another aspect to take into account is that the noise is not so strict requirement as in onshore turbines. This element allows to improve the control system of the turbines towards a higher efficiency, in particular raising the turbine rotational velocity. Figure 53 shows the power curves for different noise emissions of a Vestas offshore turbine ([12.]).

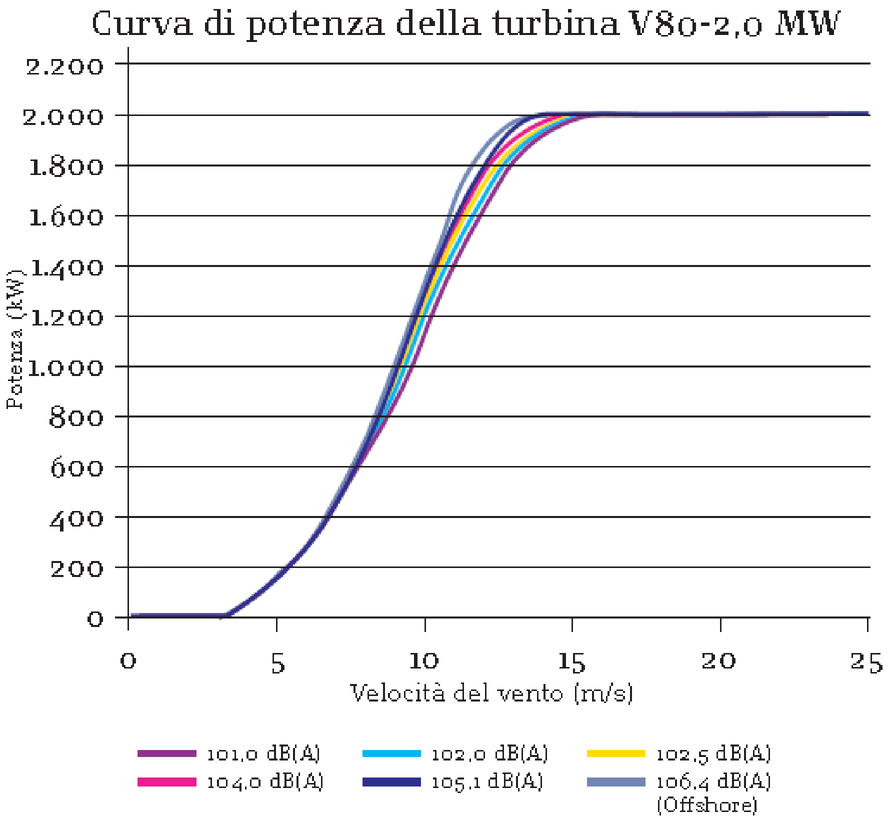


Figure 53 Power curves of a Vestas V80 for different noise emissions ([12.])

At the end of 2013 Alstom installed the 6-MW Haliade™ 150 offshore wind turbine in the waters near Ostend Harbour at the Belwind Wind Farm in Belgium (Figure 54). This is the largest offshore wind turbine ever installed in sea waters. Thanks to its 150-metre rotor (with blades stretching 73.50 metre), the turbine is more efficient since its yield is 15% better than existing offshore turbines, enabling it to supply power to the equivalent of about 5,000 households ([63.]).

The 61-metre jacket has been set on top of pillars which have been sunk to a depth exceeding 60 metres. Then the 3 elements of the 78-metre tower were gradually assembled on the jacket. In all, the nacelle towers at a height of over 100 metres above sea level. The overall weight of the turbine and its structure totals 1,500 tonnes.

This new-generation wind turbine operates without a gearbox (using direct drive). Thanks to a permanent-magnet generator, there are less mechanical parts inside the device, making it more reliable and thus helping to reduce operating and maintenance costs.

Lastly, the Haliade 150 features Alstom’s PURE TORQUE® design, which protects the generator by diverting unwanted mechanical stress towards the tower, thereby optimizing performance.

Figure 54 Alstom’s Haliade 150: 6MW wind offshore turbine at Belwind site, Belgium

In the Azimut eleven companies and 22 research centres specialising in offshore wind energy technologies have joined forces for the purpose of generating the know-how required to develop a large-scale marine wind turbine using 100% Spanish technology ([64.]).

The project, which Gamesa coordinates, involve lead partners Alstom Wind, Acciona Windpower, Iberdrola Renovables and Acciona Energía.

The initiative is designed to establish the technological groundwork for the subsequent development, in around 2020, of a large-scale offshore wind turbine. The programme’s initial objectives call for developing a turbine with unit capacity of 15 MW that is capable of overcoming the technical and financial hurdles currently limiting the rollout of offshore wind energy. The most pressing of these obstacles are availability, turbine foundations and energy delivery to land, and the challenge consists in narrowing the gap between offshore energy's cost and required investment and those of onshore wind energy sites.

At the end of 2013 the Azimut project has reached the objective of generating knowledge as well as key technologies that will enable the development of a turbine with unit capacity of 15 MW.

This project has allowed Spanish industry to reach technology leadership positions in wind energy generation in marine environments, and helping European countries to comply with the target set by the European Commission of 27% of energy consumption from renewable sources by 2030.

The different companies have obtained important results in key areas mainly developing new technologies, testing process and models and creating a new web application.

2.4 Advantage and drawbacks of offshore wind farm

Offshore locations have several advantages over land-based locations for the wind farms siting. ([13.], [14.], [15.]).

Offshore wind energy projects have one big advantage over the wind energy projects on land, namely more frequent and more powerful winds. Offshore areas provide strong winds, with less turbulence and more predictability; onshore wind is disrupted by hills or buildings, making it more turbulent and less predictable. Some recent studies have showed that offshore winds blow 40 percent more often offshore than on land which means that offshore wind farms can relatively easy outpace wind projects on land in terms of installed capacity.

The main disadvantage of offshore wind energy farms are high construction costs. Offshore wind energy projects need to be powerfully built in order to withstand rough weather conditions. Offshore wind turbines must be fixed on the seabed, which demand a more solid supporting structure. Submarine cables are needed for transmission of electricity and special vessels and equipments are required for building and maintenance work. The costs of installing an offshore wind turbine were around $5 million per megawatt of capacity in 2010, while installing turbine on land has installation costs between $2-2.5 million per megawatt of capacity. Because of this offshore wind farms need to be built on a large scale, or otherwise they are not economically viable.

Offshore wind energy market is constantly growing despite the high construction costs of new offshore wind energy projects. Some recent studies have calculated that return on investments for offshore developments can be as high as 18 percent which gives some certainty to investors, especially in combination with incentives and other tax benefits. In fact, at global level, investments in offshore wind energy sector grew by 30% in 2010 compared to the 2009.

Offshore wind technologies are still in the early phase of the development, and further technological advances should make future offshore wind energy projects much more commercially viable compared to the current offshore wind farms.

Offshore wind farms have significantly smaller negative impact on aesthetics of the landscape compared to wind farms on land because most offshore wind farms are not visible (or barely visible) from shore. From the environmental point of view, when constructing offshore wind farms constructors have to make sure to minimize any disturbancy to the nearby marine ecosystems. The constructors also must be careful not to build offshore wind farms in areas where they would interfere with shipping lanes, or in fishing areas.

Another advantage that offshore wind energy projects have over wind energy projects on land is transport. The transport of big wind turbine components such as tower sections, nacelles, and blades is significantly easier with ships as they can handle large cargo more easily than trucks or trains, and there is no traffic jam on sea like there is on land.

Offshore wind energy is clean, renewable energy source that can reduce the need for fossil fuels, and by doing so help tackle climate change and air pollution.

3 Off-shore wind energy technological and physical limits

3.1 Adriatic Sea Environmental Conditions

Climatological studies indicate that the three most prominent weather situations over the Adriatic are characterized by the airflow from northwest, southeast and northeast whose specific names are respectively etesians, sirocco and bora. The etesian winds are associated with large scale pressure gradient between the Azorean high and the Karachi depression in the warm part of the year and blow over the entire Mediterranean area. Over the Adriatic, its are primarily manifested as weak to moderate winds blowing from the northwest during the summer period. Other circulations at relatively smaller scales may frequently be super-imposed, thus modifying or strengthening the background etesian flow.

The Adriatic sirocco is related to south-eastward pressure gradient which is due to either low pressure field situated northwest or a high pressure field situated southeast of the Adriatic. It may occasionally be influenced by mesoscale cyclones in the area ([16.][18.]).

Unlike the other two winds, bora has been significantly better covered in the existing literature. It is a general practice to distinguish three bora types according to the synoptic setup: cyclonic, anticyclonic and frontal bora. Each of the three types is related to the supply of cold air from the northeast, while the direction and magnitude of pressure gradient may vary among the types.

There is an apparent symmetry between the etesian and sirocco regimes. Namely, if the etesian pressure field perturbations (deviations from the mean) would change sign, the resulting regime would closely resemble regimes with sirocco. Thus, although there would be obvious differences in magnitudes, sirocco is stronger along the north-eastern coast, while etesian winds are stronger along the south-western coast, which is due to the influence of the major mountain ridges, the Dinaric Alps for sirocco and the Apennines for etesians ([16.][18.]).

The mean of the bora–sirocco regime is clearly characterized by bora in the northern Adriatic and sirocco in the southern. However, it should be mentioned that particular episodes of bora– sirocco type can be quite different due to the extent of bora towards southeast and sirocco towards northwest. The most interesting feature of this regime is the natural appearance of the convergence zone where bora and sirocco meet. This convergence zone will have major influence on convective processes.

The structure of the bora regime is quite expected, provided the large amount of literature present on that topic. This regime is stronger along the Italian coast, northwest of Gargano, where the airflow approaching the Apennines and it is deflected towards the southeast ([16.][18.]).

Apart from the Gargano area, there are no enhanced cloudiness and precipitation regions over the Adriatic for the etesian winds, which is partly due to the dry conditions associated with this regime. Also, due to airflow from the north, cloudiness and precipitation zones are found on the eastern edges of the Dinaric Alps ([17.][18.]).

The bora regime is characterized by two regions of enhanced cloudiness, but only one precipitation maximum. Specifically, the zone of maximum precipitation as well as enhanced cloudiness is located upstream of the Apennines, and is induced by the impinging bora flow from the northeast. In that sense, the Apennines are the perpendicular mountain obstacle in the bora regime. The zone of enhanced cloudiness without significant precipitation is located upstream of the Dinaric Alps and is induced by the upstream flow from the northeast responsible for the bora generation. It is frequently relatively dry and shallow flow and hence does not produce strong precipitation ([17.][18.]).

The situation in the bora–sirocco regime is more complex. In the northern Adriatic region, the bora induces two zones with enhanced cloudiness. However, the sirocco flow from the southeast now impinges on the colder and shallower bora flow and instead of reaching the Alps it creates a convergence zone at the front between the bora and sirocco. Consequently, there is, on average, an additional zone of enhanced cloudiness above the central and northern Adriatic. The precipitation pattern is, however, influenced by the non-stationary nature of this regime, i.e. individual episodes within the regime are quite distinct ([17.][18.]).

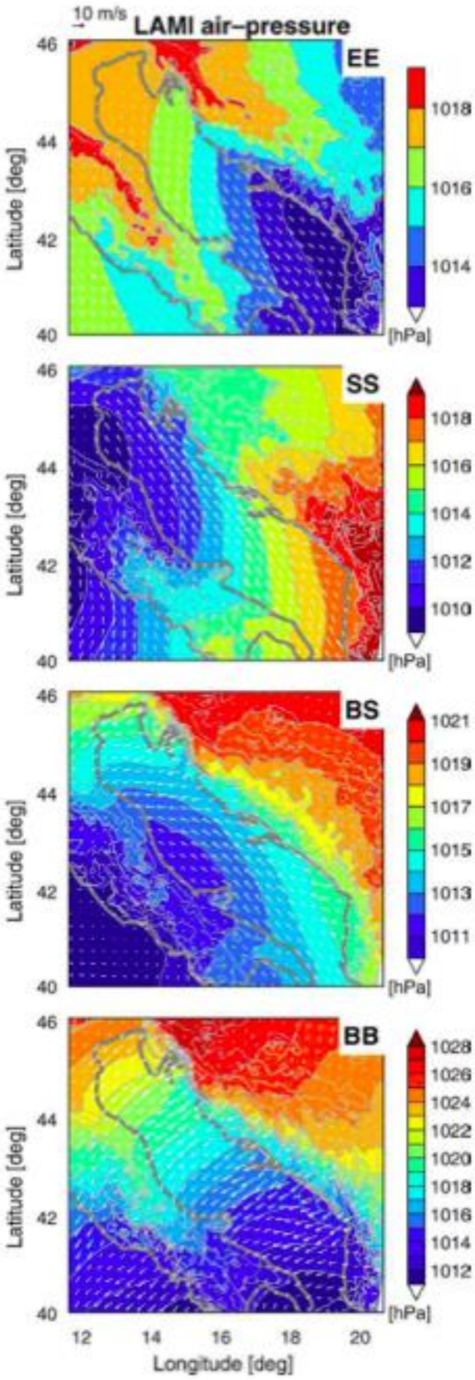


Figure 55 Mean sea level air pressure (shaded) and mean wind (vectors) calculated by LAMI (Limited Area Model Italy) over all etesian (EE), sirocco (SS), bora–sirocco (BS) and bora (BB) episodes [18.]

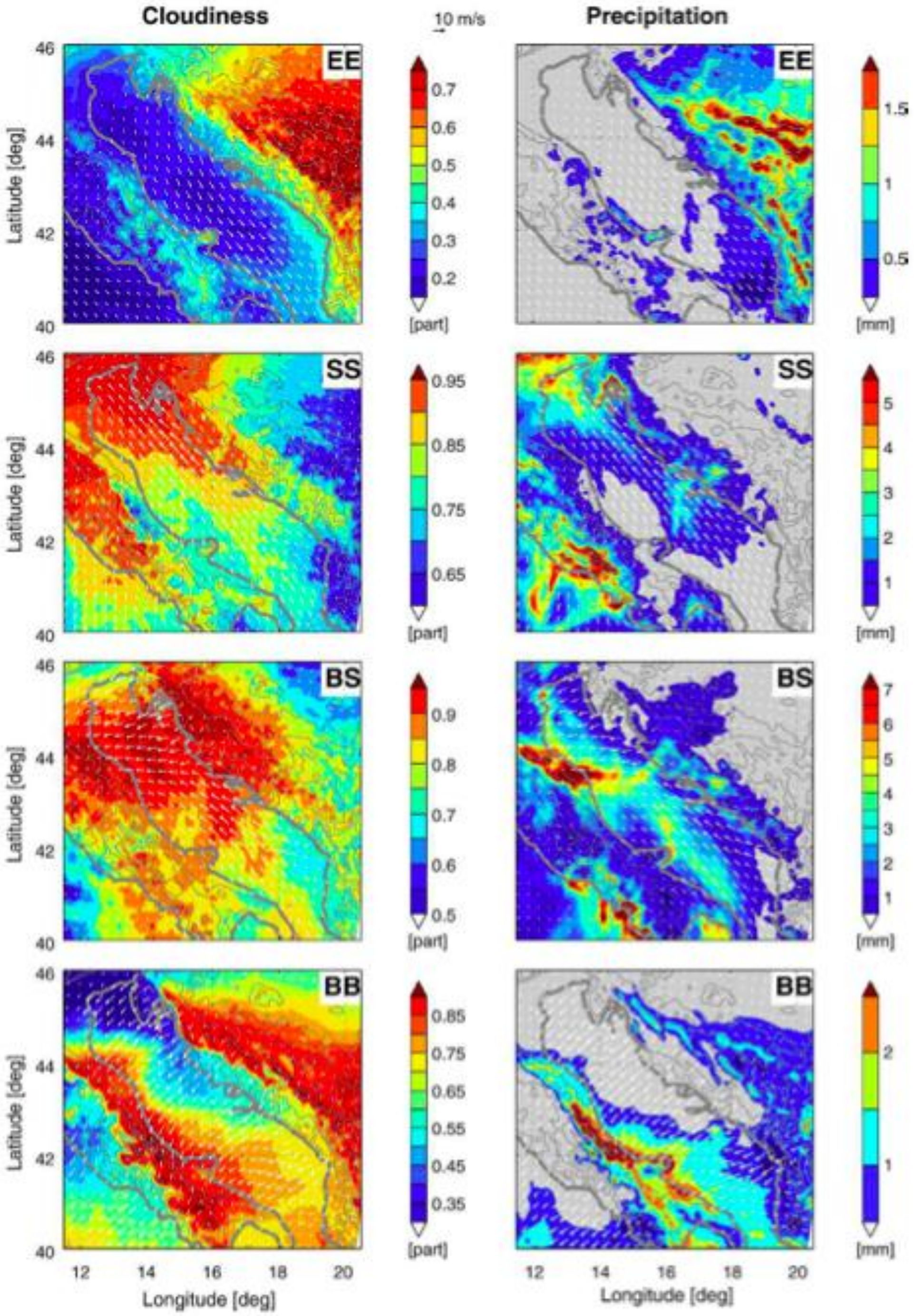


Figure 56 Mean cloudiness (left) and mean precipitation accumulated over three hour intervals (right), averaged over etesian (EE), sirocco (SS), bora–sirocco (BS) and bora (BB) episodes (shaded). Corresponding mean winds are superimposed (vectors) [18.].

3.2 Adriatic Sea Bathymetric Maps.

The Adriatic Sea (Figure 57) is a semi-enclosed basin about 750 km long and 250 km wide with a connection to the Mediterranean Sea at the Strait of Otranto (72 km wide, 780 m deep) [19.]. The knowledge of the bathymetric configuration allows to split the Adriatic area in three sub-areas. The Northern Adriatic is very shallow (the sea depth is lower than 100 m), the Middle Adriatic is occupied by a depression (the Mid Adriatic Pit, that reaches its maximum depth of 270 m) and the South Adriatic is characterized by the deepest pit of Adriatic basin (the South Adriatic Pit – 1200m).

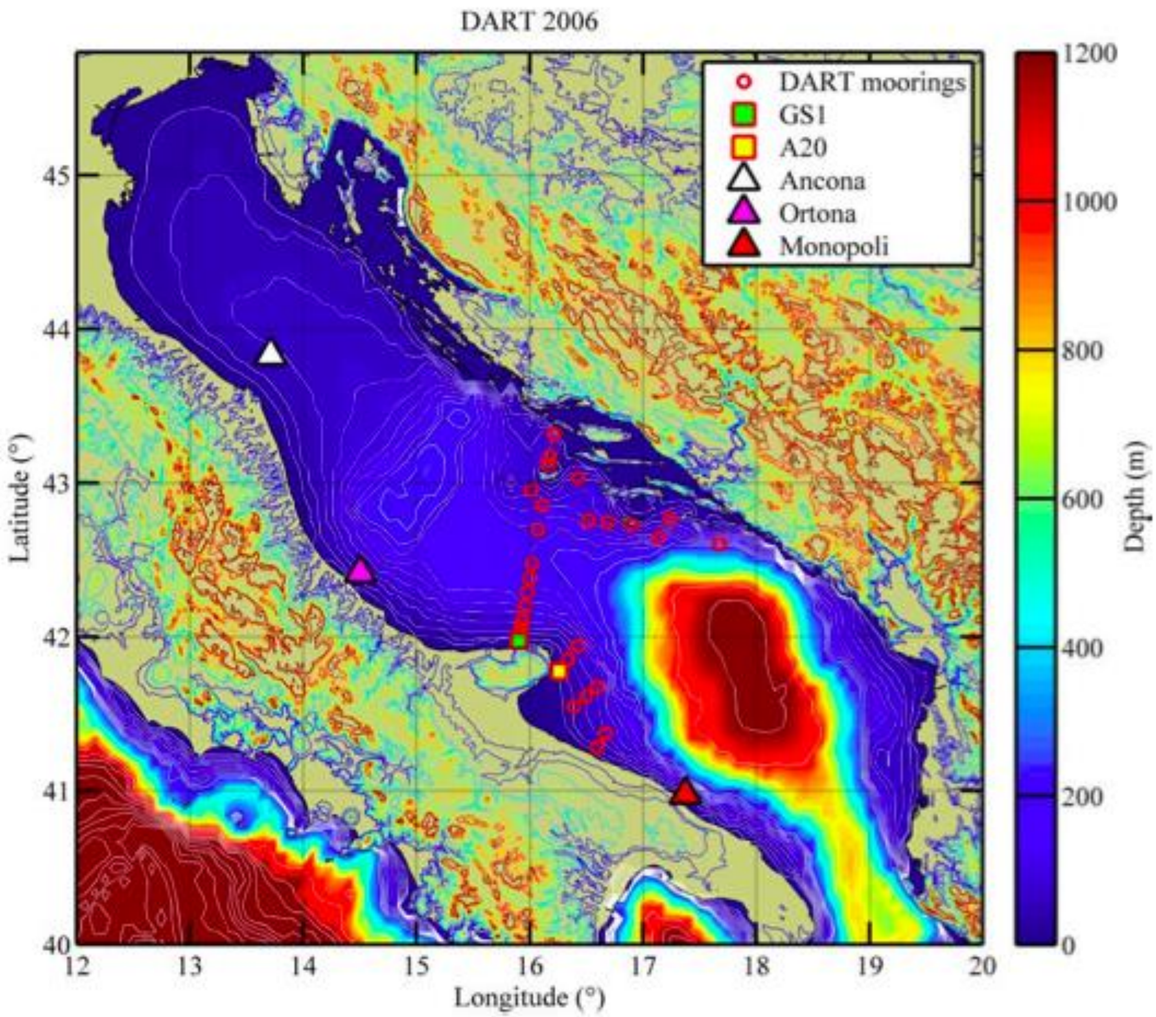


Figure 57 Bathymetry map of the Adriatic Sea

3.3 Support structure and design requirements

3.3.1 Support structure types

Offshore wind turbines are typically mounted on tubular towers that range from 60 to 105 meters above the sea surface. Lattice-type towers can also be used. The towers are fixed to the foundation, often employing a transition piece as an interface between the tower and foundation. These towers allow for the turbine to capture winds at heights far above the water's surface, where the wind resource is generally more energetic and less turbulent.

Foundation technology is designed according to site conditions. Maximum wind speed, water depth, wave heights, currents, and soil properties are parameters that affect the foundation type and design. While the industry has historically relied primarily on monopile and gravity-based foundations, the increasing number of planned projects in deeper water has motivated research and pilot installations for more complex designs with broader bases and larger footprints, such as jackets, tripods, and tripiles, to accommodate water depths exceeding 20 to 30 meters ([23.]).

In Figure 58 is showed an overview of the types of structures and foundations for Offshore Wind Turbines (OWT) .

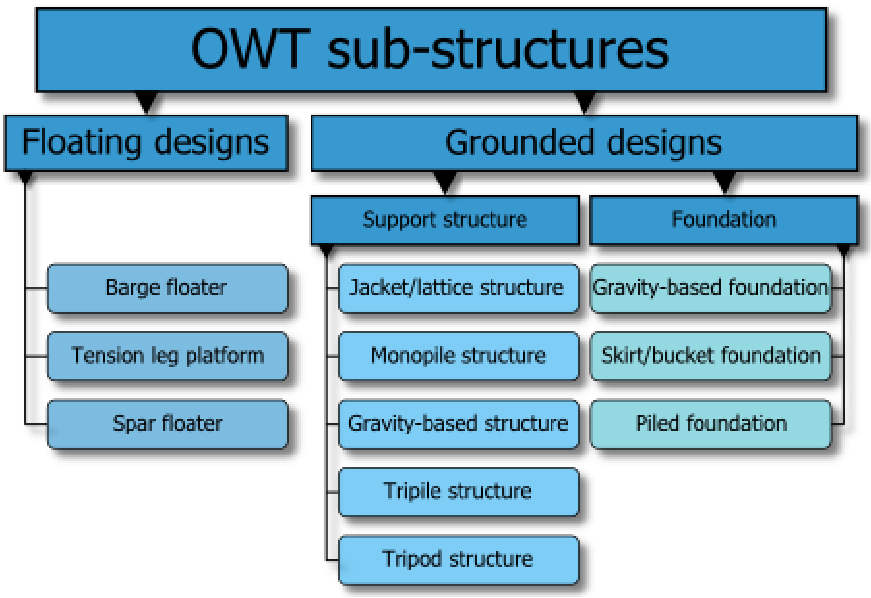


Figure 58 The different types of foundations and support structures for Offshore Wind Turbines (OWT) [21.].

Support structure concepts are basically divided into two groups: Floating or Grounded (Figure 58, [22.]).

Floating concepts imply that the support structure transfers loads and forces to the water, not the soil. Connection to the soil only ensures that the support structure stays in place.

Grounded concepts imply that the support structure transfers all loads and forces to the seabed.

The two concepts have strong differences, which make them applicable for various environments.

The pros and cons of floating concepts are:

- Pro: Large water depths – theoretically no limit
- Pro: Floating structures allow full fabrication at shipyard and transport to site in one piece.
- Con: Very expensive construction

Similarly, the pros and cons of grounded concepts are:

- Pro: Less expensive
- Pro: Large potential with water depths up to 50 meters or even deeper.
- Con: Expensive transportation and installation
- Con: Most types have only been installed in water < 25 meters.

In Table 2 the most common structures to support wind turbines are illustrated ([10.]). Monopiles have been chosen for most of the installed offshore wind farms to date. Concrete gravity base structures have also been used on several projects. As wind turbines get larger, and are located in deeper water, jacket structures are expected to become more attractive.

Table 2 Support Structure Options

Type of substructure	Brief Physical description	Suitable water depths	Advantages	Limitations
Monopile steel	One supporting	10 – 30m	Easy to manufacture, experience gained on previous projects	Piling noise, and competitiveness depending on seabed
Monopile concrete, installed by drilling	One supporting pillar	10 – 40m	Combination of proven methods, Cost effective, less environmental (noise) impact. Industrialisation possible	Heavy to transport
Gravity base	Concrete structure	Up to 40m and more	No piling noise, inexpensive	Transportation can be problematic for heavy turbines. It requires a preparation of the seabed. Need heavy equipment to remove it
Suction bucket	cylinder with sealed top pressed into the ocean floor	n.a.	No piling, relatively easy to install, easy to remove	Very sensitive to seabed conditions
Tripod	3/4-legged structure	Up to 30m and more	High strength. Adequate for heavy large-scale turbines	Complex to manufacture, heavy to transport
Jacket	Lattice structure	> 40m	Less noise. Adequate for heavy large-scale turbines	Expensive so far. Subject to wave loading and fatigue failure. Large offshore installation period therefore sensitive for weather impact
Floating	Not in contact with seabed	> 50m	Suitable for deep waters, allowing large energy potentials to be harnessed	Weight and cost, stability, low track record for offshore wind

3.3.2 Grounded concepts

3.3.2.1 Monopile Foundation.

The monopile has historically been the most commonly selected foundation type due to its lower cost, simplicity, and appropriateness for shallow water (less than 20 m). The design is a long hollow steel pole that extends from below the seabed to the base of the turbine. The monopile generally does not require any preparation of the seabed and is installed by drilling or driving the structure into the ocean floor to depths of up to 40 meters (see Figure 59). The vertical loads can easily be transferred to the soil through wall friction and tip resistance. The lateral loads, in comparison much larger, are conveyed to the foundation through bending. The loads are subsequently transferred laterally to the soil. To provide enough stiffness the diameter of the monopile foundation has to be large enough. This attracts relatively high hydrodynamic loads ([20.][22.]).

The monopile is relatively simple to manufacture, keeping its cost down despite reaching weights of over 500 tons and diameters of up to 5.1 m, which can be heavier than some more complex foundation designs.

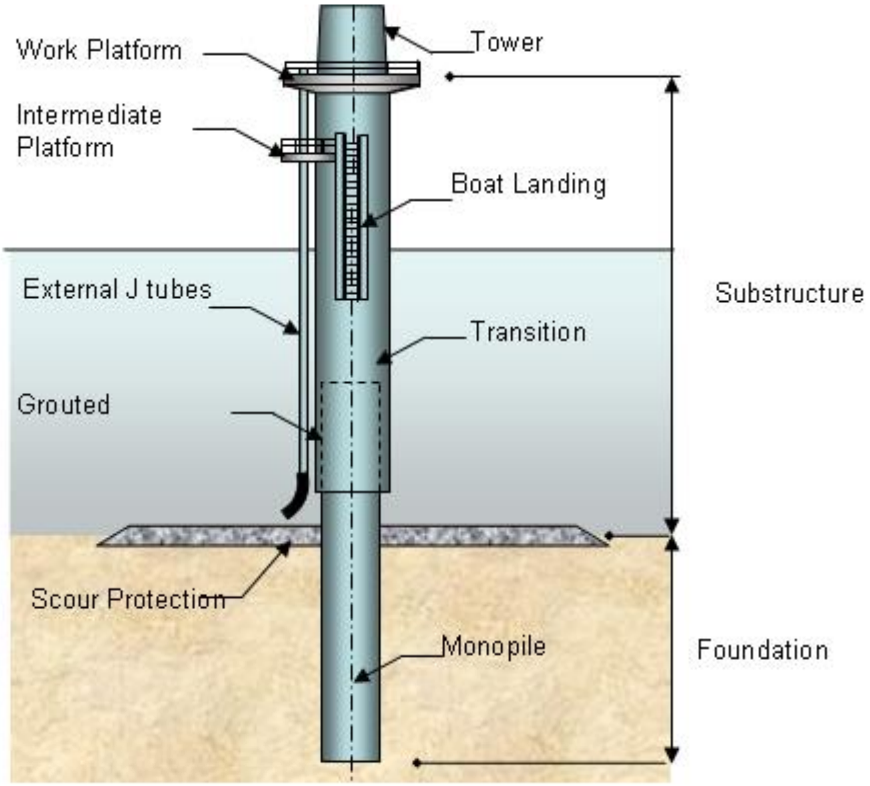


Figure 59 Monopile Foundation structure

While the monopile is an appropriate foundation choice for many projects, it can be unsuitable in some applications. These foundations are not well suited for soil strata with large boulders. Additionally the required size of an acceptable monopile increases disproportionately as turbine size increases and site conditions become more challenging. Therefore, sites with deeper water, harsh waves and currents, and larger turbines may require the implementation of more complex and sturdier designs, such as the jacket, the tripod, or the tripile ([20.][22.]).

3.3.2.2 Gravity Base Foundation

An alternative to the monopile foundation is the gravity base foundation. Historically deployed in shallow waters (usually less than 15 meters), the gravity foundation is now installed at depths up to 29 meters. This technology relies on a wide footprint and massive weight to counter the forces exerted on the turbine from the wind and waves. The gravity foundation differs from the monopile in that it is not driven into the seabed, but rather rests on top of the ocean floor. Depending upon site geologic conditions, this foundation may require significant site preparation including dredging, filling, leveling, and scour protection. It can be equipped with vertical walls that protrude from below the actual base, called skirts, which penetrate into the soil below the base. These skirts (see Figure 60 and Figure 61) increase resistance to base shear and help to avoid scour below the base. Liquefaction of the soil beneath the base due to cyclic loading is an issue that must be addressed when assessing the stability of the foundation ([20.][22.]).

These structures are constructed almost entirely on shore of welded steel and concrete. It is a relatively economical construction process, but necessitates very robust transports to deploy on-site. Once complete, the structures are floated out to the site, sunk, and filled with ballast to increase their resistance to the environmental loads. While these structures can weigh over 7,000 tons, they can be removed completely during decommissioning phase of the project.

The gravity base structure can be extended to the platform level, thereby reducing the number of offshore installation activities, as no separate transition piece needs to be installed.

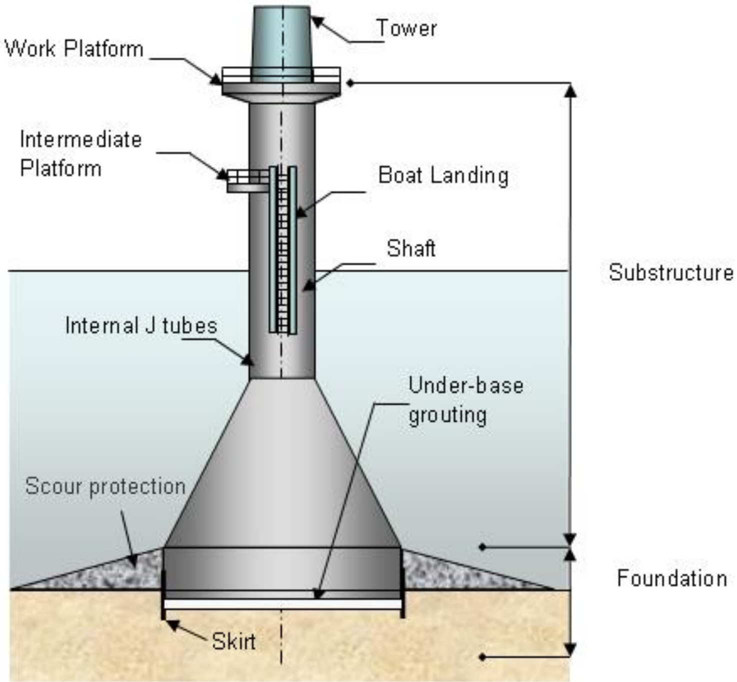


Figure 60 Gravity Base Foundation structure

Figure 61 Gravity Base Foundation

3.3.2.3 Jacket Foundation

The jacket foundation is an application of designs commonly employed by the oil and gas industry for offshore structures. The jacket structure is made up of four legs connected by slender braces, making it a highly transparent structure. Loads are transferred through the members mainly in axial direction. The legs of the jacket are set on the seabed and a pile is driven in at each of the four feet to secure the structure (see Figure 62 and Figure 63). This foundation has a wider cross-section than the monopile, strengthening it against momentary loads from the wind and waves.

Because of its geometry, the jacket foundation is able to be relatively lightweight for the strength that it offers, weighing approximately 600 tons. However, each of the joints has to be specially fabricated, requiring many man-hours of welding. Furthermore, transportation will be an issue, particularly when installing a large number of turbines. A demonstrator project has been undertaken near the Beatrice oil field off the coast of Scotland, where two 5 MW turbines are installed on jackets in 45 m water depth ([20.][22.]).

Although its design is more complex than that of a monopile, the manufacturing process is generally well understood from the offshore oil and gas industry. Once manufacturing and deployment practices can be scaled up to economically meet the needs of large projects, these foundations will likely become the predominant deeper water foundation type.

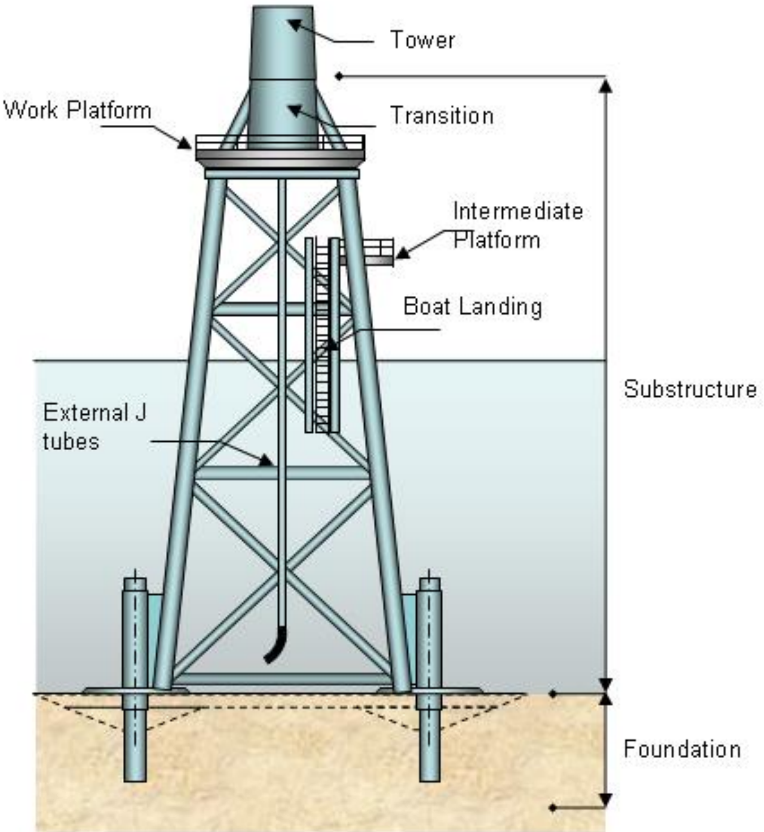


Figure 62 Jacket Foundation structure

Figure 63 Jacket Foundation

3.3.2.4 Tripod Foundation

For deep water installations, the tripod foundation adapts the monopile design by expanding its footprint. The three legs of the structure are seated on the seabed, and support a central cylindrical section that connects to the wind turbine's base. Piles are driven through each of the three feet to secure the structure to the bed (see Figure 64 and Figure 65). The main difference between the tripod and the monopile concepts is the way the loads are transferred to the seabed. From the main joint downwards the transfer of loads relies mainly on axial loading of the members. The piles are also mainly loaded axially. This allows the tripod foundation to be shallower and lighter than the monopile foundation. Furthermore, the tripod has a larger base, which gives it a larger resistance against overturning. The base is also stiffer, leading to an overall stiffer structure. However, the main joint is a complex element that is susceptible to fatigue and requires much effort in designing and engineering. From an installation point of view, the tripod poses challenges as it cannot be transported as easily as a monopile foundation ([20.][22.]).

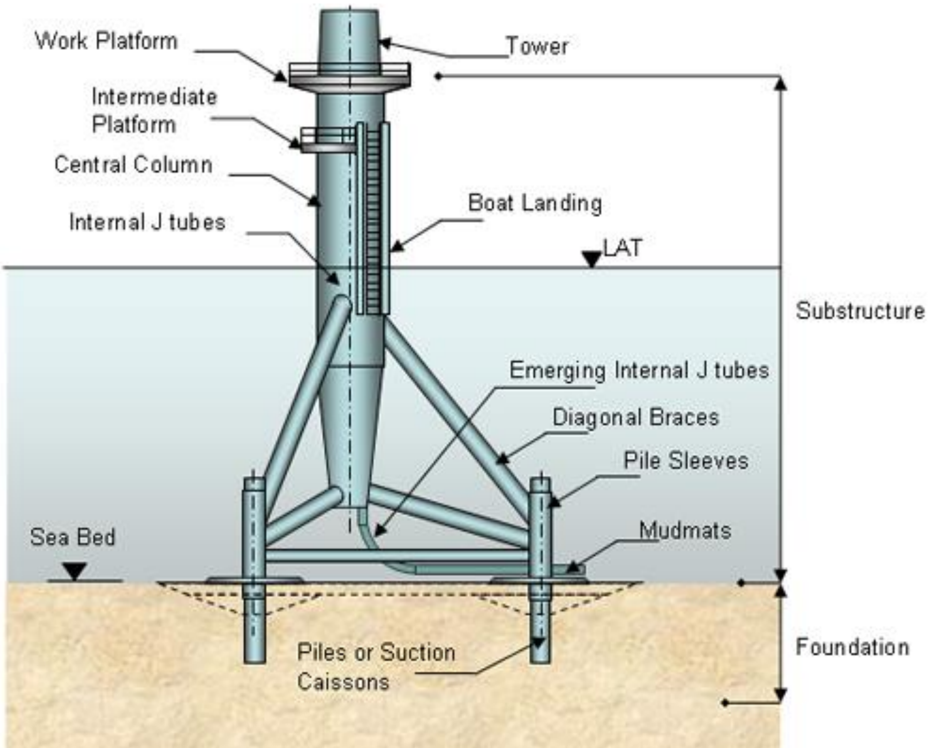


Figure 64 Tripod Foundation structure

Figure 65 Tripod Foundation

3.3.2.5 Tripile Foundation

The tripile foundation is also a relatively new adaption of the traditional monopile foundation. Instead of a single beam, three piles are driven into the seabed, and are connected just above the water's surface to a transition piece using grouted joints (see Figure 66). This transition piece is connected to the turbine tower's base. The increased strength and wider footprint created by the three piles is expected to allow for turbine installation in water up to 50 meters in depth. The tripile design is easily adaptable to a variety of conditions, as each or all of the piles can be manufactured appropriately to match site-specific conditions while still being connected to the standard transition piece ([20.][22.]).

Figure 66 Tripile Foundation

3.3.2.6 Suction bucket foundations

The suction bucket concept is a monotower with a suction bucket at its base. A suction bucket is a large diameter cylinder with a closed top. It is installed by placing it on the seabed and subsequently activating a pump that removes water from within the suction bucket (Figure 67). This creates a pressure difference with respect to the ambient pressure, which results in a downward force. This causes the suction bucket to be pressed down into the soil. Once the pump is deactivated skin friction and end bearing will keep the foundation in place and provide the required bearing capacity. Because it is reliant on the pressure difference for installation, this concept is not suitable for very shallow water. It may be practical to integrate the suction bucket with the transition piece to reduce the number of offshore installation activities ([20.][22.]).

Depending on soil conditions encountered at a site, the suction bucket alternative may be preferable to deep slender piles for economic reasons and for ease of installation.

Figure 67 The prototype for Horns Rev 2 site (North Sea, Denmark). It weighs 165 tons, the skirts are 12 meters in diameter and 6 meters in height.

3.3.3 Floating concepts

The rapid growth of offshore wind in Europe has led to the realization that it is necessary to capture the better wind resources existing further from shore in deeper waters and with larger turbines. It is also necessary for industry to cut the cost of delivered wind power below current levels. Reaching both of these goals will make the net cost of wind energy competitive with landbased wind power, and set the stage for reaching fossil fuel energy prices in the not-too-distant future.

The current fixed-bottom jacket structures increase in cost with and complexity with increased water depth. At about 65 meters of water depth, the floating foundations become cost competitive with fixed-bottom structures.

Currently, Spars, Semi-submersible and Tension Leg are the three primary categories used in the offshore wind farms, adapted from the offshore oil and gas industry.

3.3.3.1 Semi-submersible platforms

A floating structure relies on buoyancy to keep the turbine above the water. Different configurations, again derived from the oil and gas industry, can be envisaged. For instance; a turbine could be placed on a barge and attached to the seabed with anchor lines. The anchor line configuration can be either catenary or taut. The mooring can be completed using drag anchors, driven piles or suction anchors. The offshore wind turbine can be assembled on the barge floater at an onshore location. The assembly can be towed out to the required location. This concept may be suitable for large scale production as it can easily be adapted to different water depths. However, it may require at least a certain depth before the mooring concept can be applied. Furthermore, a barge type floater may have serious motion issues. Its large cross section at the water line makes it sensitive to hydrodynamic loads, which in turns makes it susceptible to heave, pitch, roll and sway ([20.]).

3.3.3.2 Tension Leg Platforms (TLP)

Another option for a floating structure is a mini Tension Leg Platform (TLP), which is tethered to the seabed by means of pre-tensioned cables. The pre-tension greatly reduces heave motion and to a certain extent horizontal motion. The cables can be fixed to a template on the seabed or to individual piles or suction buckets. The TLP has a small cross section at the water line, keeping the hydrodynamic loads relatively small. The TLP requires well engineered connections of the cables to the floater. The tension legs will not be very suitable for shallow water ([20.]).

3.3.3.3 *Spar Floater (ballast stabilized system)*

A spar type floating structure obtains its buoyancy from a cylinder that protrudes below the water line. This cylindrical body is generally long and slender in order to minimize the cross section at the water line. This greatly reduces the wave induced motion. It can be anchored to the seabed with chains in a catenary shape. A spar typically has a small surface cross-section, reducing heave motion. The draft of a spar is usually relatively large to ensure sufficient buoyancy. This may pose problems in small water depths. Because of this the spar may not be very cost effective for shallow water ([20.]).

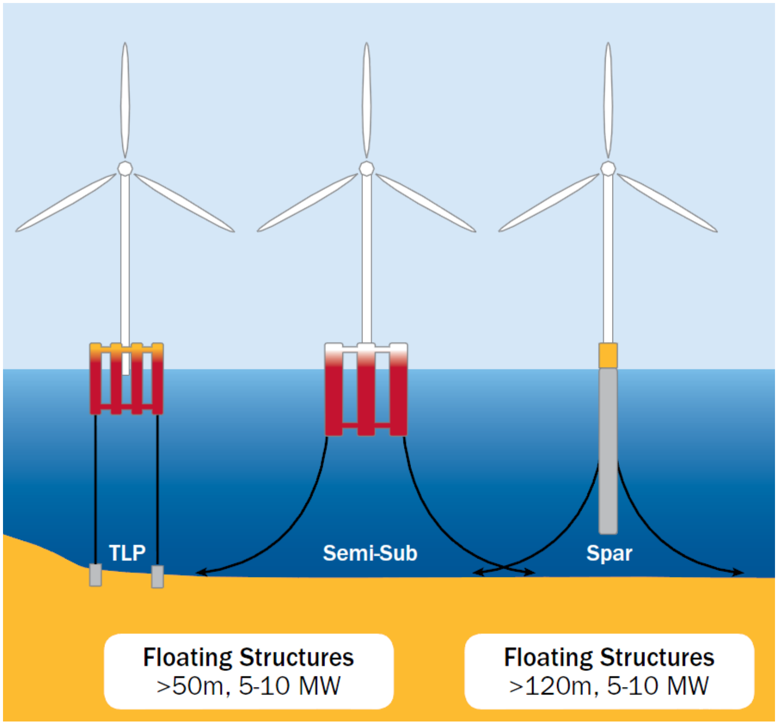


Figure 68 Floating foundation design concepts

3.3.3.4 *Demonstrators*

Numerous floating foundation design concepts are emerging and being presented to the industry:

- the Blue H Technologies of the Netherlands (Figure 69) consists of a buoyant body held semi-submerged in the water by chains connecting the buoyant body to a counterweight that lies on the seabed. The concept was demonstrated through full installation and testing in 2007 in a water depth of over 100 m, approximately 17 km offshore from Puglia, Italy. It generated 80 kW and after a year of testing and data collection it was decommissioned.

Blue H Engineering is now executing the design, engineering works and related applied research for the development of a generic 5 MW model, based on proven Tension Leg Platform technology. This will offer a more stable floating foundation for commercially available 5-7 MW wind turbines. The manufacturing demonstrator is planned for 2015 and the commercial model is planned for 2016.

Figure 69 Blue H technology

- the Hywind concept from Statoil Hydro (Figure 70), consists of a spar floater filled with ballast. This floating element extends 100 metres beneath the surface and is fastened to the seabed by three anchor piles. The turbine itself is built by Siemens. The total weight is 1500 tonnes. The 2.3 MW Hywind demo was installed in Norway in 2009 - the world's first full scale floating offshore wind turbine. The unit is located at a water depth of 200m, 10km off Norway's west coast. It has been thoroughly inspected after the first and second years in service, and no signs of deterioration, damage, or wear connected to being on a floater have been reported. The floater design has been optimised and up-scaled for deployment with multi-MW turbines in the 3 MW to 7 MW range. The next step will be to test the design in a pilot farm with four to five units.


Figure 70 The Hywind concept (on the left) and prototype installed at 10 kilometres south-west of Karmøy (Norway)

- the Sway concept (Figure 71) is developed in partnership with Statkraft and Shell. The Sway system is a floating foundation capable of supporting a 5 MW wind turbine in water depths ranging from 80 m to more than 300m. In the Sway system, the tower is stabilised by elongation of the floating tower to approximately 100m under the water surface and by around 2000 tons of ballast in the bottom. A wire bar gives sufficient strength to avoid tower fatigue. Anchoring is secured with a single tension leg between the tower and the anchor. In March 2011, Sway deployed the floating wind turbine prototype in 1:6 scale near Bergen (Norway). The SWAY prototype has a 13-meter (m) downwind rotor on a 29-m tower, with a large portion of the tower beneath the ocean surface. In June 2012, the National Renewable Energy Laborator (NREL) sent staff members to Norway to install scientific equipment on the seabed and on the prototype above the water line to collect data that will help validate a computer model of the SWAY design. The instruments on the seabed will collect information such as wave height and direction, tidal variations and sea temperatures. Instrumentation installed on the turbine prototype above the water will collect atmospheric data such as wind speed and direction and operational data such as platform motions, loads, and performance. SWAY hopes these data will validate its design for a 10-megawatt floating offshore wind turbine ([66.]).

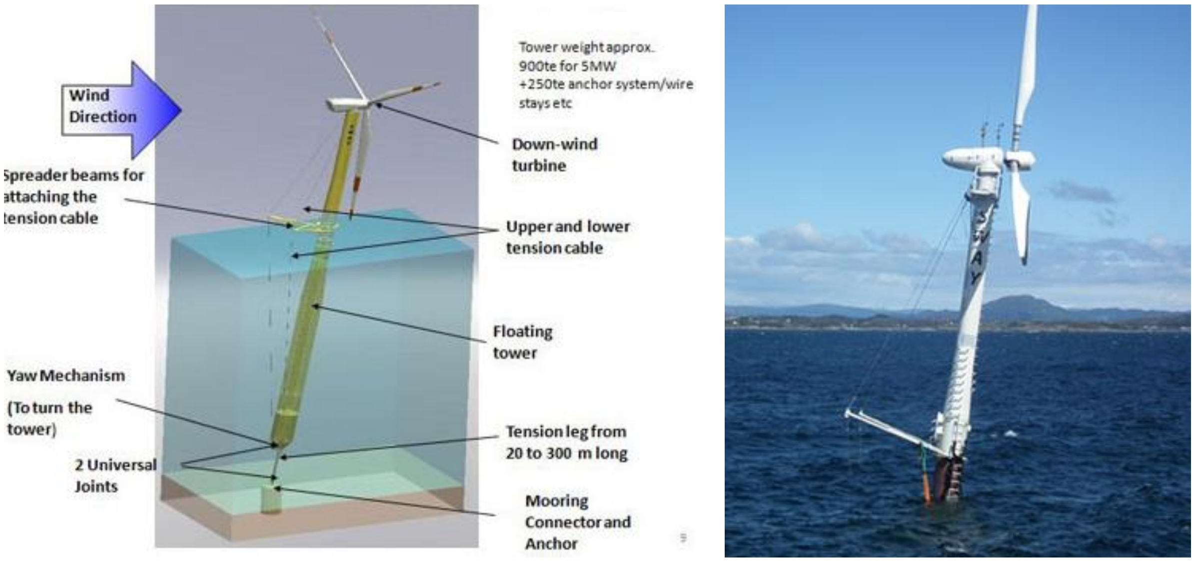


Figure 71 The Sway technology (on the left) and prototype in 1:6 scale (on the right)

- WindFloat is a floating support structure for offshore wind turbines with a simple, economic and patented design. The innovative features of the WindFloat dampen wave and turbine induced motion, enabling wind turbines to be sited in previously inaccessible locations where water depth exceeds 50m and wind resources are superior. Further, economic efficiency is maximized by reducing the need for offshore heavylift operations during final assembly deployment and commissioning ([65.]). The WindFloat concept consists of a semi-submersible floater fitted with water entrapment (heave) plates at the base of each column that improve the motion performance of the system due to damping and entrained water effects. In addition, WindFloat's closed loop hull trim system mitigates wind induced thrust forces. This secondary system ensures optimal energy conversion efficiency following changes in wind velocity and directions. The design of the WindFloat enables the structure to be fully assembled onshore and towed to its final location. All fabrication and qualification is completed at quayside in a controlled environment. Deployment cost savings are significant when compared with monopile/jacket support structures which require offshore heavylift operations.

The mooring system employs conventional components such as chain and polyester lines to minimise cost and complexity. Through the use of pre-laid drag embedded anchors, site preparation and impact is minimised. In October, 2011, Principle Power deployed a full-scale prototype WindFloat 4km off the coast of Aguçadoura, Portugal (Figure 72). Equipped with a 2 MW Vestas wind turbine, the installation started producing energy in 2012. To date the system has produced in excess of 9 GWh of elctricity delviered by sub-sea cable to the local grid. The next step will be to build a 27 MW array off Portugal. Another 30 MW demonstration project is also planned off Oregon in the Pacific Ocean.

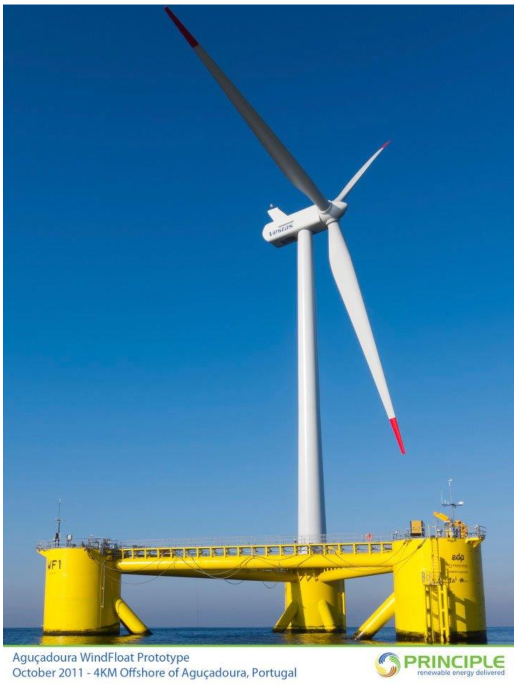
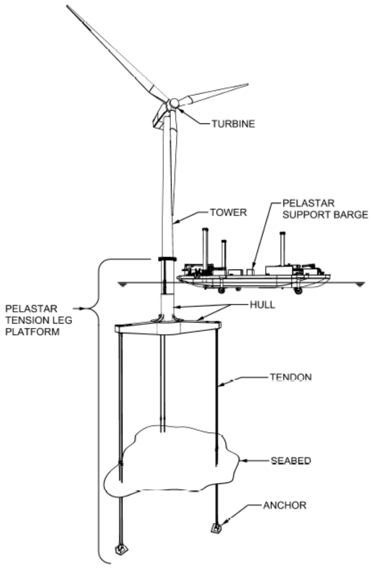


Figure 72 WindFloat prototype

- PelaStar is a tension-leg platform (TLP) integrating proven TLP technology, widely used in the offshore oil and gas industry, and is being adapted for the offshore wind industry. The PelaStar floating offshore wind turbine technology represents the new generation of deep-water wind turbine foundations. PelaStar is a unique combination of existing technologies and innovative engineering solutions that provides low cost access to the high quality wind energy resources found in water depths greater than 65 meters. The PelaStar system has the best technical performance and the lowest cost of energy when compared to alternative designs. The PelaStar solution has a projected cost of energy well below the 65 meter jacket structures, and even lower than the best-in-class monopile bottom-fixed turbines in Europe ([67.]). The PelaStar system was conceived in 2006, by Naval Architects at The Glosten Associates. Various platform types were considered, and the TLP emerged as the clear leader due to its potential for a low structural weight, an in-harbor system assembly method and superior dynamic responses to sea conditions (Figure 73-a). The low motion response of the TLP maximizes turbine performance on a floating structure. Model testing at 1:50 scale was completed in 2011 (Figure 73-b). Key outcomes included verification of the system dynamic behavior in ocean conditions with an operating turbine, confirmation that PelaStar's mooring tendons are feasible and cost-effective at intermediate and full scale and extensive collaboration with wind power experts, offshore industry specialists, and world-leading researchers. In 2012, Glosten was selected by the Energy Technologies Institute (ETI) to design an offshore wind floating platform system demonstrator. The goal of the project was to accelerate the market introduction of floating foundations for deep water offshore wind farms and to break down technical barriers for deployment. Glosten completed a front end engineering design of the PelaStar tension leg platform to support an Alstom 6 MW Haliade 150 turbine. The Glosten-Alstom team worked closely to model the vessel motion interactions with the turbine and design a capable foundation. Teams of top-tier subcontractors were contracted to develop hull construction, anchor installation, tendon manufacture, site installation and operations, and maintenance plans. A full cost of energy study was also prepared that applied the detailed demonstrator project cost data to predict the future cost of energy of floating wind farms over a wide range of UK offshore sites. The final design was delivered in February of 2014, and results show that UK offshore wind energy costs could fall to below £85/MWh by the mid-2020s, with further reductions possible as this technology matures. The PelaStar 6 MW demonstrator has been designed for installation in the Celtic Sea off Cornwall. The designed structure reaches 180 m from blade tip to waterline and will operate continuously in the harsh conditions of the North Atlantic. Rock anchor systems, tendons and connectors, hull fabrication and transport, assembly, installation and operations have all been designed, planned, and costs estimated for the construction phase ([68.]).

a) 

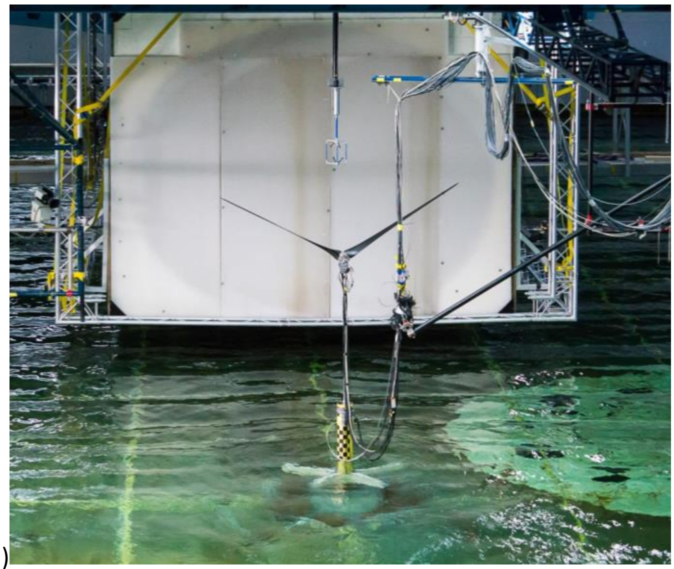
b) 

Figure 73 The PelaStar Offshore Floating Wind Turbine (a) and the 1:50-scale model (b)

- Winflo is an innovative semi-submersible floater with a lightweight wind turbine specially designed for the floating offshore system and a specific anchoring system with few constraints suitable to all types of seabed (Figure 74). The Winflo (Wind turbine with INnovative design for Floating Lightweight Offshore) programme is led by DCNS together with Nass&Wind, a major actor in the wind-turbine sector which has recognised experience in the development of sites and the financing, construction and operation of wind farms. The aim of programme is to develop the first generation of floating wind turbines in France. The 1MW demonstrator has been designed to adapt to the specific conditions of the SEM-REV site, which has a depth of 35 metres with significant waves and a constrained anchoring radius. Its achievement constitutes a first step towards larger-scale industrial deployment. Commercial operation will start after the test phase of a pilot farm comprising four to six units. This farm will be installed in 2017 off the coast of the Ile de Groix (Morbihan county in Brittany). The final goal is to develop the first commercial floating wind-turbine farm by 2020 ([69.]).

Figure 74 Winflo concept

- IDEOL platform is a ring-shape surface floater with a shallow draught and very compact dimensions. Thanks to the exceptional dynamic behaviour of the Damping Pool® system, developed and patented by IDEOL, the floating foundation is compatible with any commercial offshore wind turbines without modification. Based on a construction in concrete, the IDEOL solution can scale to mass production for very large wind farms, with on-site construction, high local content and versatile construction methods, depending on site conditions and local procurement options. Thanks to its reduced cost, the IDEOL floating foundation is competitive with bottom-fixed ones starting from 35 meters water depth. It has been designed following the highest safety standards and rely exclusively on offshore oil & gas proven and qualified components. IDEOL has completed the design phase of its floating foundation. A full test campaign has been conducted to validate the floater, mooring and turbine behavior under the most stringent conditions in controlled environments. The company is tightly working with classification societies in order to validate the design, has completed technical review and validation with key partners and suppliers. Thousands of hours of simulation have also been conducted to test and validate each components under operating conditions using proven oil&gas and wind turbine software simulation tools. IDEOL has secured the partnerships and financing required for the industrialisation phase. In particular the company is working with key partners and market leaders on the installation of a 2MW demonstrator in 2015 and a pilot farm in 2017-18. The 2 MW demonstrator is realized in partnership with GAMESA and benefits from a 10 M€ grant from the European Commission. Finally, the company is working with key suppliers to qualify new components and further reduce its floating foundation costs in the context of its 2020 technical roadmap ([70.]).

a)  b) 

Figure 75 IDEOL floating foundation (a) and the scale model (b)

- The Hexicon Energy Design is based on a semi-submersible platform on which are installed several wind turbines (Figure 76-a). It is configured to pick-up a minimum amount of energy from the waves in order to be as stable as possible. The basic idea at Hexicon was to attach the mooring in a central turret and turn the whole platform, so that the wind always comes from one direction. Hexicon is based in Stockholm and designs, engineers and optimizes the concept of floating wind energy parks. The Hexicon floating platform design uses competence and components that already exist and are well proven in harsh sea environment. However the combination of these components is new. There are many advantages with Hexicon's platforms compared to traditional bottom mounted wind turbines, e.g. large scale deployment far offshore and less amount of individual site engineering in a park. Also main components will be installed in shipyards or quayside, there is less offshore installation and operation compared to traditional parks, all turbines benefit from free wind and the mooring system is well proven (Figure 76-b). Further, only one power cable per platform reduces the amount of array cabling, platform depth is between 40 m to 1000m, sea bed conditions are not critical, the environmental footprint is small, the platform can be relocated and can be renovated in port ([71.]).

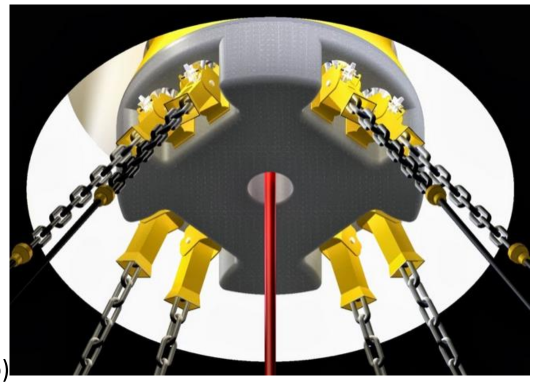
a)  b) 

Figure 76 Hexicon semi-submersible platform design (a) and mooring systems (b)

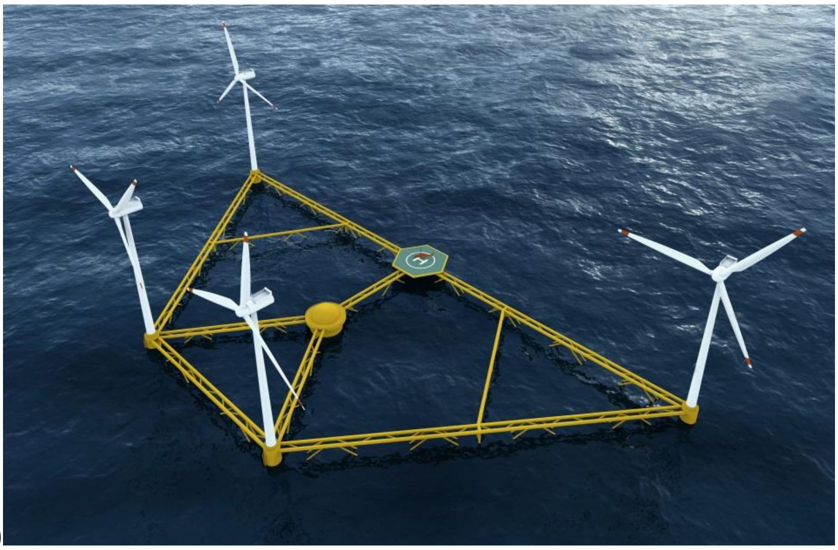
Hexicon is currently developing a number of reference projects to be in production within the next five years. The Swedish reference project is a floating platform with

3x6 MW to be located in the southern Baltic sea, in the concession owned by Blekinge Offshore. This project is planned for construction in 2016-2018 and Hexicon has been allocated an area in the concession where the water depth is about 45 m. The Scottish reference project with 3x6 MW is based in northern Scotland. The Scottish Government has a special incentive program for floating wind energy demonstrators. Hexicon is preparing applications for this program. The platform will be designed and sized for the harsh environment of the North Sea. Another project is being planned at the Canary Islands by the island of Gran Canaria, where the water depth is around 250m. A wind energy platform combined with a desalination plant in the Black Sea has been offered to supply the city of Istanbul with fresh water. This solution could be attractive for islands and nations with water shortage. Producing fresh water with wind energy also solves the problem of storing energy, since freshwater can be stored more easily. Several other markets in Asia, Europe and USA are being pursued, but the lead time to build floating wind energy parks with Hexicon's platforms may be longer.

In the following figure showed the Hexicon platforms that have reached conceptual design status: H3W-18MW, H3-18MW and H4-24MW ([72.]).

a)

b)



c)

Figure 77 Hexicon platforms concepts: H3W-18MW (a), H3-18MW (b) and H4-24MW (c)

In the HiPRwind R&D project the European Commission awarded an 11 M€ grant to a consortium of 19 partners (Figure 78) coordinated by Fraunhofer IWES, in order to develop new structural, component, monitoring and control engineering solutions that will enable very large wind power installations in deeper waters than possible today. In order to gain real sea experience and data, a fully functional floating MW-scale wind turbine will be deployed at a European ocean test site (Figure 79). This MW-scale test installation is approximately 1:10 scale of the future commercial systems. In this way, the project will overcome the current gap in technology development between small scale tank testing and full scale offshore deployment. The HiPRWind project will make use of existing test locations which offer a favourable permitting situation and infrastructure such as grid connection and monitoring facilities already in place.

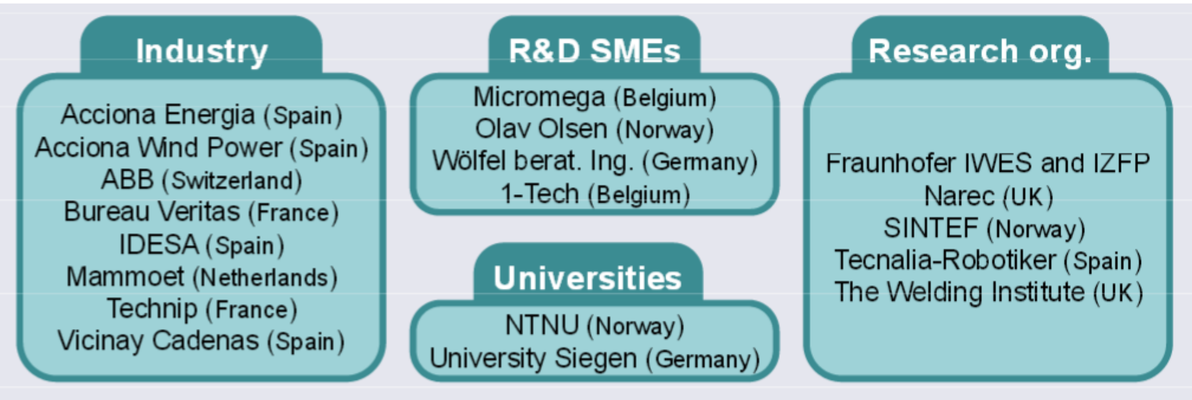


Figure 78 HiPRWind project: consortium of partners

The installation of the world's first large scale floating wind turbine facility, dedicated to shared access research and testing, will allow to address critical issues of deep offshore wind technology such as innovative floater designs, efficient installation methods, advanced control engineering solutions and grid integration aspects of floating wind turbines. At the same time this research addresses the need for extreme reliability of components. Innovative engineering methods will be applied to selected development challenges such as rotor blade designs, structural health monitoring systems, reliable power electronics and control systems. Built-in active control features will reduce the dynamic loads on the floater in order to save weight and cost compared to existing designs.

HiPRWind will significantly reduce the risks and costs of commercializing deep water wind technology. The HiPRWind project is funded within the 7th Framework Programme of the EC. It started in November 2010 and will continue through the end of 2016 ([73.]).

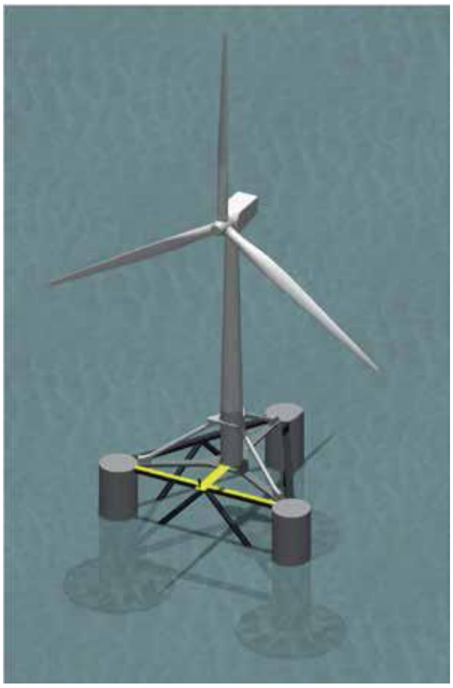


Figure 79 HiPRWind floating wind turbine concept

3.3.4 Design requirements

The design of an offshore wind project is based on the environmental conditions to be expected at a proposed site over the project's lifetime (typically 20 or more years). These environmental conditions are primarily defined by the wind, wave, current, water depth and soil and seabed characteristics ([23.]).

Different project components are more sensitive to some of these characteristics than others. For example, a wind turbine's rotor and nacelle assembly are most sensitive to wind and other atmospheric conditions while the support structure (tower and foundation) design is more dependent on hydrodynamic and seabed conditions.

Wind turbine models tend to be designed for applicability for a specified range of wind conditions whereas turbine support structures are usually engineered for onsite conditions.

3.3.4.1 Standards and Certifications

Several design guidelines and standards have been developed nationally and internationally that apply to wind turbines, wind turbine foundations and offshore structures. Germanischer Lloyd (GL), Det Norske Veritas (DNV), and TUV Nord are among the bodies that offer certification and guidelines for offshore wind turbines and related components and processes. Additionally, the IEC 61400-3 International Standard Design Requirements For Offshore Wind Turbines (2008) provides criteria for offshore site conditions assessment, and establishes five critical design requirements for offshore wind turbine structures (i.e. winds, waves, currents, on site data collection, seabed characteristic and water depth). These guidelines were developed to ensure that type-certified wind turbines, support structures and related processes meet the requirements dictated by the site conditions.

3.3.4.2 Winds

Wind conditions are important in defining not only the loads imposed on all of a turbine's structural components, but also in predicting the amount of future energy production at different time scales. The measured on-site wind resource strongly influences the layout of turbines within a defined area as a function of the prevailing wind direction(s). Desired wind data parameters include the following:

- Wind speed – annual, monthly, hourly, and sub-hourly; preferably at hub height
- Speed frequency distribution – number of hours per year within each speed interval
- Wind shear – rate of change of wind speed with height
- Wind veer – change of wind direction with height
- Turbulence intensity – the standard deviation of wind speeds sampled over a 10-min period as a function of the mean speed
- Wind direction distribution

- Extreme wind gusts and return periods (50 and 100 year).

Air temperature, sea surface temperature and other meteorological statistics (icing, lightning, humidity, etc.) are also desired when evaluating a proposed site.

3.3.4.3 Waves

In addition to the loading forces imposed on a turbine's support structure, waves also determine the accessibility of offshore projects by vessels during construction and operations. Desired wave data parameters (Figure 80) include the following:

- Significant wave height
- Extreme wave height
- Maximum observed wave height
- Wave frequency and direction spectra
- Correlation with wind speeds and direction

Waves tend to be irregular in shape and height and may approach a wind turbine from more than one direction simultaneously. The probability and characteristics of breaking waves are also important. The correlation of wind and waves is a critical design criterion for an offshore wind turbine. This correlation is normally expressed as a joint probability of wind speeds and wave heights, and may include wave frequency as well. In addition to defining extreme aerodynamic and hydrodynamic loads, it is important to assess the dynamic vibrations induced upon the entire turbine structure. The effects of resonant motion from certain wind and wave loads may be a primary design driver.

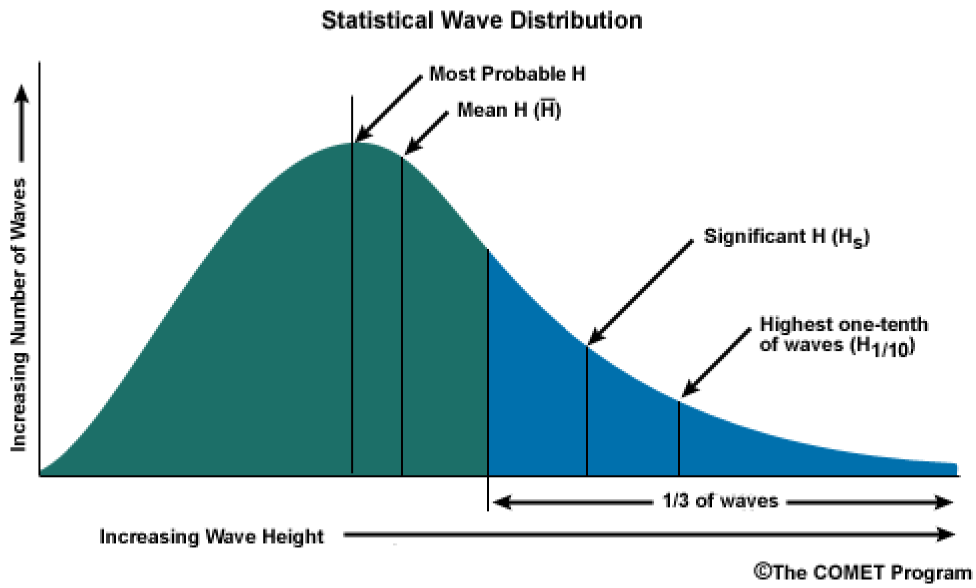


Figure 80 Statistical Wave Distribution and Data Parameters

3.3.4.4 Currents

Currents are generally characterized either as sub-surface currents produced by tides, storm surges, and atmospheric pressure variations, or as near-surface currents generated by the wind. Currents can drive sediment transport (e.g. sand waves) and foundation scouring. They can also affect sea bottom characteristics and vessel motion during construction or service visits.

3.3.4.5 Onsite Data Collection

As accurate estimations of energy production potential are requirements by the financial community for offshore wind projects, precise definition of all of these atmospheric and aquatic parameters is critical.

These parameters can be derived from various sources depending on the stage of project development. Early stage conceptual planning relies mostly on existing climatological data and model results (such as wind maps). Advanced stages rely on on-site measurement campaigns lasting 1 – 3 years.

Meteorological, wave and current data are monitored using a variety of instrumentation.

Atmospheric data is measured by tall meteorological masts installed on offshore platforms to assess the site's wind resource for both energy assessment and maximum loading purposes. These measurements can be complemented by remote sensing devices (such as lidar and sodar), weather buoys, and regional weather observations to assess atmospheric conditions throughout and surrounding the project area.

Wave and current data are collected by instrumented buoys and acoustic Doppler current profilers (ADCPs). Additional information acquired from specialized radar and satellite data, as well as regional and historic surface data sources, can further characterize the offshore environment.

Additional information on data meaurements techniques are reported in par 5.1.

3.3.4.6 Seabed Characteristics and Water Depth

The geologic and bathymetric characteristics of a project site are significant design parameters for offshore wind turbines. The site bathymetry (water depth) will primarily drive the size of the underwater structure and its exposure to hydrodynamic forces, whereas the seabed soil properties and profiles will influence the suitable foundation types. From a system perspective, the geologic and bathymetric characteristics help determine the axial and lateral pile responses, load-carrying capabilities, resonant frequencies, ultimate strength, fatigue strength, and acceptable deformation of the offshore support structure.

A geologic survey of the site often begins with a desktop review of available data to understand conditions likely found on-site. Detailed design and engineering work involves a multi-step on-site investigation process, including seismic reflection methods combined with soil sampling and penetration tests. These techniques obtain information about sediment characteristics and stratification to depths of at least 60 meters (200 feet) below the sea floor. Sediment and subsurface descriptors include the following:

- Soil classifications
- Vertical and horizontal strength parameters
- Deformation properties
- Permeability

- Stiffness and damping parameters – for prediction of the dynamic behavior of the wind turbine structure.

3.4 Offshore Wind Turbine Technological and Energetic features

3.4.1 The main turbine models

The two most important manufacturers of offshore wind turbines are Siemens and Vestas, which together produce 86% of the global offshore capacity. Siemens, which bought the Danish company Bonus, is the leader of offshore wind turbines industry with 715 machines installed in 20 different wind farms, corresponding to 49% of the total operating turbines. Vestas follows with 545 turbines in 17 wind farms and a share of 37%. Also BARD plays a considerable role, with 80 turbines and 400 MW of offshore wind capacity, that is with a share of 6%.

Table 3 shows the most offshore wind turbine manufactures, whereas in Figure 81 is shown the national breakdown of active offshore wind turbines for different manufacturers ([4.]).

Table 3 Main offshore wind turbine manufactures

Manufactures	Nationality	Number of wind farms	Number of turbines	Turbine models
Siemens	Germany	20	715	2.3-82; 2.3-93; 2.3-101; 3.6-107; 3.6-120; Bonus 450 kW
Vestas	Denmark	17	545	V39-500; V47-660; V66-2.0; V80-2.0; V90-3.0
REpower	Germany	3	14	5M
Nordex	Germany	2	2	N90-2300
NEG Micon	Denmark	2	33	NM72/2000
WinWind	Finland	2	20	WWD-3
BARD	Germany	2	81	5.0
GE Wind	US	2	14	GE 3.6 Offshore
Goldwind	China	1	1	GW70/1500
Sinovel	China	1	34	SL3000/90
Subaru	Japan	1	7	80/2.0
Enercon	Germany	1	1	E-112

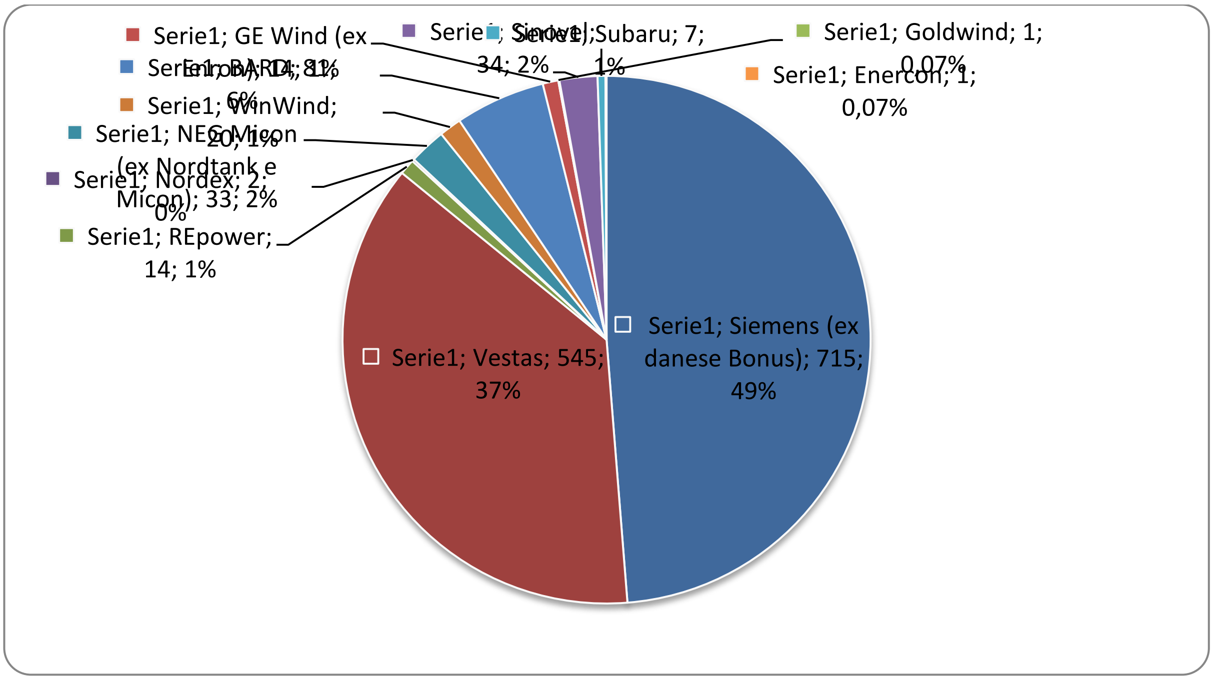


Figure 81 Breakdown of active offshore wind turbines for different manufacturers.

Siemens is present offshore with 6 turbine models:

- 2.3-82
- 2.3-93
- 2.3-101
- 3.6-107
- 3.6-120
- Bonus 450 kW

Of these the most representative of the dominant technology are Siemens 2.3-93 and 3.6-107, respectively, with a rated power of 2.3 MW and 3.6 MW. Today these are among the most popular models: there are 250 2.3-93 units and 343 3.6-107 units operational.

Vestas is present offshore with these 5 models:

- V39-500
- V47-660
- V66-2.0
- V80-2.0
- V90-3.0

Of these turbines the 2 MW V80-2.0 MW and the 3 MW V90-3.0 are dominant, respectively with 216 and 319 operating units.

Considering the trend of the market in recent years to bigger investments and higher power levels, the following high-power turbines gain in importance:

- REpower 5M from 5 MW
- BARD 5.0 from 5 MW
- GE Wind 3.6 Offshore 3.6 MW
- Enercon E-112 4.5-MW

The tables below highlight the main technical features of the mentioned offshore turbines (data from [4.]).

SIEMENS

Siemens 2.3-93

Rated Power pr. Turbine	2.3 MW
Number of Turbines	91
IEC Wind Turbine Class	IEC IA
Operational	
Cut-in Wind Speed	4 m/s
Rated Wind Speed	13.5 m/s
Cut-out Wind Speed	25 m/s
Rotor & Hub	
Rotor Diameter	93 m
Rotor Area	6793 m2
Rotor Speed (rated)	16 rpm
Rotor Weight (incl. hub)	60 t
Hub Height (above sea level)	68 m
Blade Tip Speed (rated)	77.9 m/s
Blade Tip Height (above sea level)	114.5 m
Pitch System	Hydraulical
Nacelle	
Drive Train Type	High Speed
Gearbox Ratio	1:91
Gearbox Stages	3 Planetary, 1 Helical
Gearbox Manufacturer	Winergy
Generator Type	**Asynchronous**
Power Converter Type	Full Scale
Yaw Gears - Number	8
Nacelle Weight	
(without rotor and hub)	82 t
Tower	
Structure Type	Tubular
Structure Material	Steel

SIEMENS

Siemens 3.6-107

Rated Power pr. Turbine	3.6 MW
Number of Turbines	140
Design Life	25 years
Operational	
Cut-in Wind Speed	4 m/s
Rated Wind Speed	13.5 m/s
Cut-out Wind Speed	25 m/s
Rotor & Hub	
Rotor Diameter	107 m
Rotor Area	8992 m2
Rotor Speed (rated)	13 rpm
Rotor Weight (incl. hub)	95 t
Hub Height (above sea level)	77.5 m
Blade Tip Speed (rated)	72.8 m/s
Blade Tip Height (above sea level)	131 m
Pitch System	Hydraulical
Nacelle	
Drive Train Type	High Speed
Gearbox Ratio	1:119
Gearbox Stages	3 Planetary, 1 Helical
Generator Type	Asynchronous with squirrel-cage rotor
Generator Poles	4 poles
Power Converter Type	Full Scale
Yaw Gears - Number	6
Dimensions of Nacelle	
Length	20 m
Width	10 m
Height	10 m
Nacelle Weight	
(without rotor and hub)	125 t
Tower	
Structure Type	Tubular
Structure Material	Steel
Height	57 m
Weight	250 t

Vestas®

Vestas V90-3.0

Rated Power pr. Turbine	3 MW
Number of Turbines	100
IEC Wind Turbine Class	IEC IA
Design Life	20 years
Operational	
Cut-in Wind Speed	3.5 m/s
Rated Wind Speed	15 m/s
Cut-out Wind Speed	25 m/s
Rotor & Hub	
Rotor Diameter	90 m
Rotor Area	6362 m2
Rotor Speed (rated)	16.1 rpm
Rotor Speed (max)	18.4 rpm
Hub Height (above sea level)	70 m
Blade Tip Speed (rated)	75.9 m/s
Blade Tip Speed (max)	86.7 m/s
Blade Tip Height (above sea level)	115 m
Pitch System	Hydraulical
Nacelle	
Drive Train Type	High Speed
Gearbox Ratio	1:104
Gearbox Stages	2 Planetary, 1 Helical
Generator Type	**DFIG**
Generator Poles	4 poles
Power Converter Type	DFIG
Turbine Voltage Level	1000/400 V
Yaw Gears - Number	6
Dimensions of Nacelle	
Length	9.65 m
Width	3.85 m
Height	4 m
Tower	
Structure Type	Tubular
Structure Material	Steel
Weight	153 t

Vestas V80-2.0

Rated Power pr. Turbine	2 MW
Number of Turbines	80
IEC Wind Turbine Class	IEC IA
Operational	
Cut-in Wind Speed	4 m/s
Rated Wind Speed	16 m/s
Cut-out Wind Speed	25 m/s
Rotor & Hub	
Rotor Diameter	80 m
Rotor Area	5027 m2
Rotor Speed (rated)	16.7 rpm
Rotor Speed (max)	19.1 rpm
Hub Height (above sea level)	70 m
Blade Tip Speed (rated)	70.0 m/s
Blade Tip Speed (max)	80.0 m/s
Blade Tip Height (above sea level)	110 m
Weight pr. Blade	6.5 t
Pitch System	Hydraulical
Nacelle	
Drive Train Type	High Speed
Gearbox Ratio	1:100.5
Gearbox Stages	2 Planetary, 1 Helical
Generator Type	**DFIG**
Generator Poles	4 poles
Turbine Voltage Level	690/480 V
Yaw Gears - Number	6
Dimensions of Nacelle	
Length	10.4 m
Width	3.4 m
Height	5.4 m
Nacelle Weight	
(without rotor and hub)	79 t
Tower	
Structure Type	Tubular
Structure Material	Steel
Weight	160 t

REpower 5M

Rated Power pr. Turbine	5 MW
Number of Turbines	2
Design Life	20 years
Operational	
Cut-in Wind Speed	3.5 m/s
Rated Wind Speed	14 m/s
Cut-out Wind Speed	30 m/s
Rotor & Hub	
Rotor Diameter	126 m
Rotor Area	12469 m2
Rotor Speed (rated)	12.1 rpm
Rotor Speed (max)	13.9 rpm
Rotor Weight (incl. hub)	125 t
Hub Height (above sea level)	87 m
Blade Tip Speed (rated)	79.8 m/s
Blade Tip Speed (max)	91.8 m/s
Blade Tip Height (above sea level)	148 m
Weight pr. Blade	17.5 t
Pitch System	Electrical
Nacelle	
Drive Train Type	High Speed
Gearbox Ratio	1:97
Gearbox Stages	2 Planetary, 1 Spur
Generator Type	**DFIG**
Generator Poles	6 poles
Power Converter Type	DFIG
Turbine Voltage Level	950/660 V
Yaw Brake Type	Hydraulical
Tower	
Structure Type	Tubular
Structure Material	Steel
Height	59 m
Weight	225 t
Foundational Structures	
Structure Type	Jackets
Support Structure Material	Steel
Support Structure Supplier	Burnt Island Fabrication

BARD 5.0

Rated Power pr. Turbine	5 MW
Number of Turbines	80
Design Life	20 years
Operational	
Cut-in Wind Speed	3 m/s
Rated Wind Speed	12.5 m/s
Cut-out Wind Speed	25 m/s
Rotor & Hub	
Rotor Diameter	122 m
Rotor Area	11690 m2
Rotor Speed (rated)	12.5 rpm
Rotor Weight (incl. hub)	155.5 t
Hub Height (above sea level)	90 m
Hub Weight	70 t
Blade Tip Speed (rated)	79.8 m/s
Blade Tip Height (above sea level)	152 m
Weight pr. Blade	28.5 t
Nacelle	
Drive Train Type	High Speed
Gearbox Ratio	1:96.965
Gearbox Stages	2 Planetary, 1 Helical
Generator Type	**DFIG**
Power Converter Type	DFIG
Dimensions of Nacelle	
Length	14 m
Width	8.5 m
Height	8 m
Nacelle Weight	
(without rotor and hub)	280 t
Tower	
Structure Type	Tubular
Structure Material	Steel
Height	63 m
Weight	450 t
Structure Description	Diameter is 6.5 m (bottom) og 5.5 (top)

GE Wind 3.6 MW

Rated Power pr. Turbine	3.6 MW
Number of Turbines	7
IEC Wind Turbine Class	IEC IB
Operational	
Cut-in Wind Speed	3.5 m/s
Rated Wind Speed	14 m/s
Cut-out Wind Speed	27 m/s
Rotor & Hub	
Rotor Diameter	104 m
Rotor Area	8495 m2
Rotor Speed (max)	15.3 rpm
Hub Height (above sea level)	73.5 m
Blade Tip Height (above sea level)	124 m
Pitch System	Electrical
Nacelle	
Drive Train Type	High Speed
Gearbox Stages	3 Planetary, 1 Spur
Generator Type	**DFIG**
Power Converter Type	DFIG
Tower	
Structure Type	Tubular
Structure Material	Steel
Height	70.5 m
Weight	160 t
Supplier	Bladt Industries
Structure Description	Diameter is 5 m (bottom) and 3 m (top)

Enercon E-112

Rated Power pr. Turbine	4.5 MW
Number of Turbines	1
Operational	
Cut-in Wind Speed	2.5 m/s
Rated Wind Speed	13 m/s
Cut-out Wind Speed	28 m/s
Rotor & Hub	
Rotor Diameter	112 m
Rotor Area	9852 m2
Rotor Speed (max)	13 rpm
Hub Height (above sea level)	108 m
Blade Tip Speed (max)	77.6 m/s
Nacelle	
Drive Train Type	Direct Drive
Generator Type	Synchronous
Generator Manufacturer	Enercon
Power Converter Type	Full Scale
Turbine Voltage Level	400 V
Yaw Gears - Number	8
Tower	
Structure Type	Tubular
Structure Material	Concrete
Height	100 m
Weight	2500 t
Structure Description	Diameter is 4 m (top) and 12 m (bottom)

3.4.2 Wind Conditions and Wind Turbine Classes

The design of a wind turbine shell ensure the appropriate level of reliability for its correct operation and specified durability, in every load condition. The sources of loading on a wind turbine can be divided into the following:

- Aerodynamic loads
- Gravitational loads
- Inertia loads (due to the blades rotation)
- Operational loads (depending on the electrical conditions, the control operations, e.g. braking, yawing, emergency procedures)

They depend on the turbine characteristics and on the external conditions that are mainly the electrical power network conditions and the wind conditions.

The international standard for safety requirements of wind turbine generators ([24.][25.]) divides the external conditions into normal and extreme categories. The normal external conditions generally concern recurrent structural loading conditions, while the extreme external conditions represent rare external design conditions (as having a 1-year or 50-year recurrence period). The design load cases shall consist of potentially critical combinations of these external conditions with wind turbine operational modes and other design situations.

Wind conditions are the primary external conditions affecting structural integrity. Other environmental conditions also affect design features such as control system function, durability, corrosion, etc.

3.4.2.1 Small Wind turbine (SWT) classes ([25.])

The external conditions to be considered for design are dependent on the intended site or site type for a SWT installation. SWT classes are defined in terms of wind speed and turbulence parameters. The intention of the classes is to cover most applications. The values of wind speed and turbulence parameters are intended to represent many different sites and do not give a precise representation of any specific site. The wind turbine classification offers a range of robustness clearly defined in terms of the wind speed and turbulence parameters. Table 4 specifies the basic parameters, which define the SWT classes. A further

SWT class, class S, is defined for use when special wind or other external conditions or a special safety class are required by the designer and/or the customer.

The design values for the SWT class S shall be chosen by the designer and specified in the design documentation. For such special designs, the values chosen for the design conditions shall reflect an environment at least as severe as is anticipated for the use of the SWT.

The particular external conditions defined for classes I, II, III and IV are neither intended to cover offshore conditions nor wind conditions experienced in tropical storms such as hurricanes, cyclones and typhoons. Such conditions may require wind turbine class S design.

Table 4 Basic parameters for SWT classes

SWT class	I	II	III	IV	S
V_{ref}(m/s)	50	42,5	37,5	30	Values specified by the designer
V_{ave} (m/s)	10	8,5	7,5	6	
I_{15}	0,18				

In Table 4, the parameter values apply at hub height and

V_{ref} is the reference wind speed averaged over 10 min,

V_{ave} is the annual average wind speed,

I_{15} is the dimensionless characteristic value of the turbulence intensity at 15 m/s. The turbulence intensity is the ratio of the wind speed standard deviation to the mean wind speed, determined from the same set of measured data samples of wind speed, and taken over a specified period of time ([25.]).

3.5 Transmission and electric grid connection systems

The outstanding growth of the offshore wind farms size (up to the 630 MW London Array Phase 1), along with their distance to shore, has given to the design of the electric transmission system a crucial importance in terms of offshore economical feasibility. Longer transmission lines lead to higher investment costs as well as higher energy losses. However in some cases offshore wind energy can be an opportunity to bring the electric production closer to large urban centers of energy consumption. An interesting challenge in this regard would be to coordinate offshore wind projects with the expansion strategies carried by electricity network operators.

Onshore and offshore wind turbines have at most a generator voltage level of 690 V, a transformer in the nacelle, or at the basement, which is used to increase the generator voltage to the medium voltage of the wind farm network. The current standard for offshore wind power plants is 33÷36 kV. However their increasing size and distances will require AC networks with a bigger voltage in the next future, that will result in larger and more expensive transformers. A possible solution to contain the transformer size may consist of high voltage electric generators (e.g. 4000 V) ([26.]).

In cases of offshore wind parks at large distance from the coast (> 10 km) it is adopted the solution of the voltage transformer station at sea. These stations enable high voltage transmission and therefore greater efficiency. Two examples of this type are:

- Horns Rev (Denmark): 160 MW installed capacity, park voltage at 36 kV, offshore transformer platform (the first in history) that rises to 150 kV for a 15 km AC transmission line.
- Nysted (Denmark): 165.6 MW installed capacity, park voltage at 33 kV, offshore transformer platform that rises to 132 kV for a 10 km AC transmission line to the coast.

The design of the layout of offshore wind farms is influenced by the prevailing wind direction, the seabed morphology, but also by the electrical transmission design. For instance it should be considered the option of redundancy in the power connection to the coast, in order to achieve the transmission reliability.

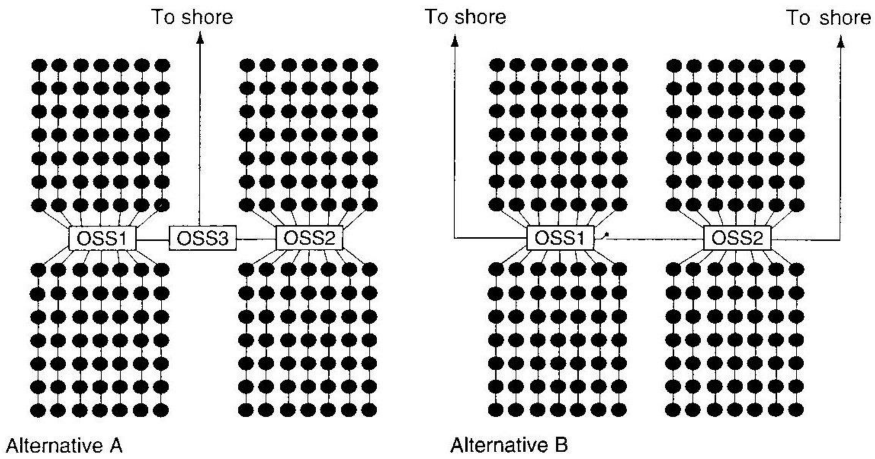


Figure 82 A) Solution with one offshore transformer station (OSS3) and B) solution with 2 transformer stations and 2 lines to the coast ([26.]).

3.5.1 Transmission Systems: HVAC, HVDC-LCC, HVDC-VSC

Main technologies of transmission to the coast are ([26.]):

- HVAC (High Voltage Alternating Current): transmission through high-voltage AC current.
- HVDC - LCC (High Voltage Direct Current, Line Commutated Converter): transmission through high-voltage DC current, with power conversion using line commutated thyristors.
- HVDC - VSC (High Voltage Direct Current, Voltage Source Converter): transmission through high-voltage DC current, with power conversion using a pulse width modulation with IGBT.

3.5.1.1 HVAC Systems

The scheme of HVAC transmission systems is composed of:

- an AC based collector system within the wind farm
- an offshore transformer station, possibly accompanied by a reactive power compensation system. With increasing distances compensation is necessary

- three-phase transmission line. At a voltage level of 150 kV three-core polyethylene insulation cables are used (XLPE). At very high voltage levels (400 kV) three separate cables are used instead
- onshore transformer station that transforms the voltage at the local network levels. This includes a compensation unit.

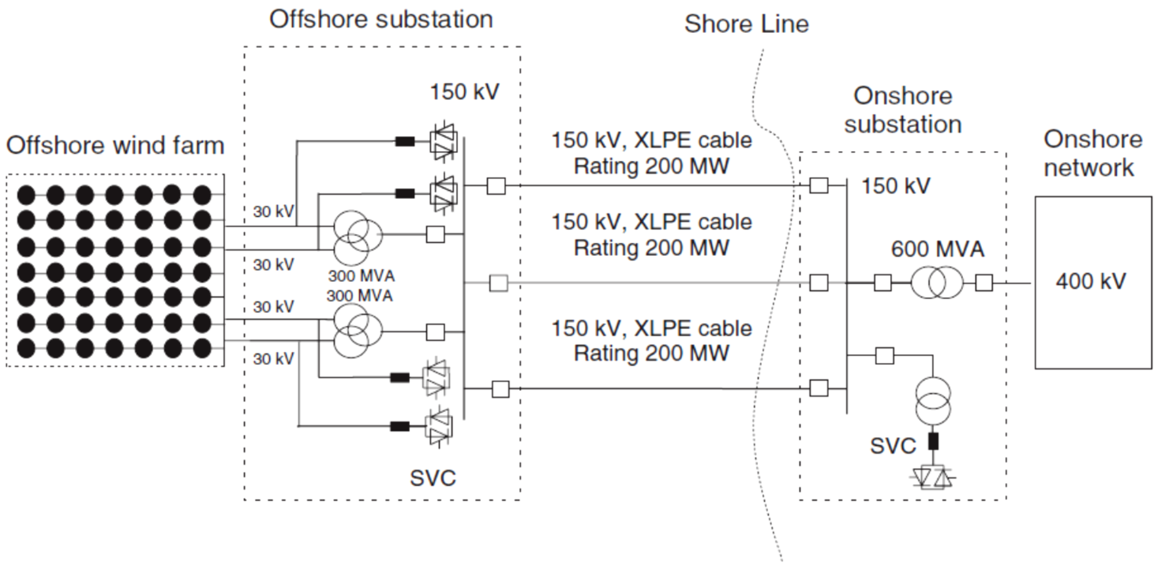


Figure 83 Basic scheme of a connection between an HVAC offshore wind farm and the main electricity grid ([26.]).

The transmission capacity of cables, at 150-170 kV, reaches 200 MW every three-phase connection, while the maximum length is 200 km, using reactive power compensation on both sides of the line. The 400 kV technology, which is under development, promises instead a cable capacity of 1200 MVA, over a maximum distance of 100 km ([26.]).

Almost all current operating offshore parks adopt alternating current transmission because the distances from the coast and the power of the plants are still quite limited. The main advantage of this technology is the low cost of voltage transformation and its compact converter stations. On the other hand they have the disadvantage that with longer distances energy losses become much larger, in particular because of the capacitive phenomena concerning submarine cables.

3.5.1.2 HVDC-LCC systems

The line commutated DC current technology makes use of thyristor-based power converters. It is used for long geographical distances and high levels of power, e. g. between the islands of Japan. This system is composed of:

- an AC based collector system within the wind farm
- an offshore substation with two three-phase two-winding converter transformers, filters, a capacitor or a STATCOM (or a diesel generator). The STATCOM provides the necessary switching voltage to the converter, and compensates the reactive power for offshore grid in all conditions (stationary, dynamic, etc..)
- DC cable(s) with return cable
- onshore converter station with a single-phase three-winding converter transformer and the appropriate filters

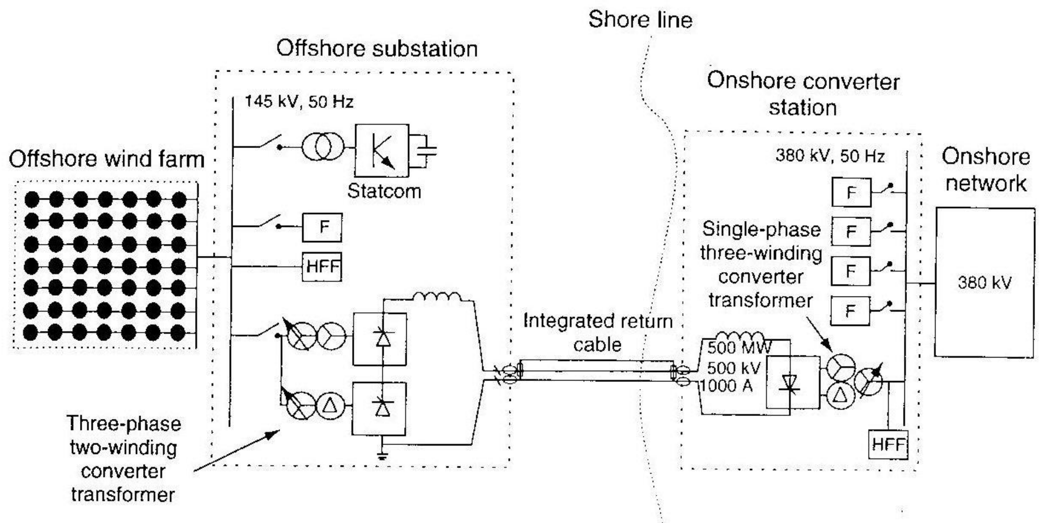


Figure 84 Basic scheme of LCC HVDC connection between an offshore wind farm and the main electricity grid [26.]).

The HVDC-LCC technology requires large converter stations. The offshore station has to include also auxiliary services, such as diesel generators: LCC converters need electricity supply even when there is not wind energy production.

3.5.1.3 HVDC-VSC systems

This direct current technology uses a more advanced high power electronics: the insulated gate bipolar transistors (IGBT), with pulse width modulation. This is a technology developed in recent years (the first installation was in 1997) and marketed by ABB (HVDC Light) and Siemens (HVDC Plus). The German offshore wind farm BARD is based on VSC-HVDC: it is equipped with two 125 km submarine cables of the type ABB HVDC Light ([27.]). The system consists of:

- an AC based collector system within the wind farm
- an offshore transformer substation with VSC converter
- two DC cables (there is no ground connection)
- an onshore converter station

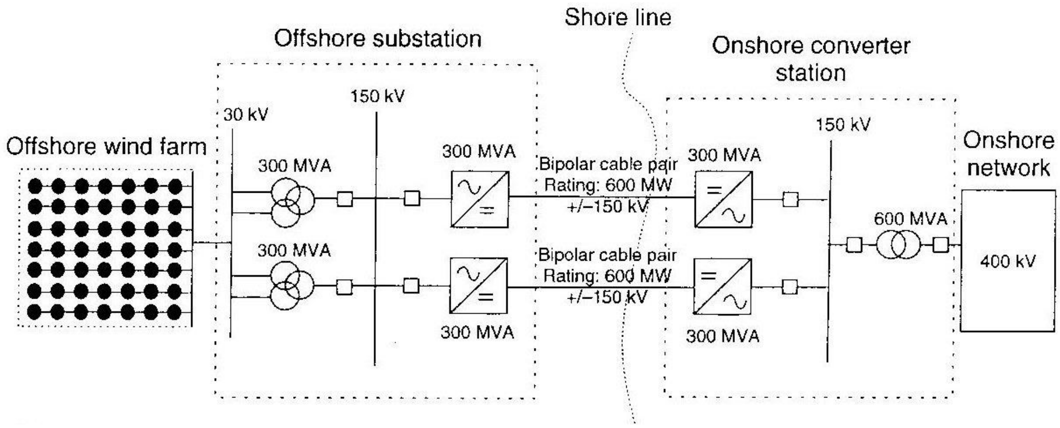


Figure 85 Basic scheme of the VSC-HVDC connection between an offshore wind farm and the main electricity grid ([26.]).

The major advantage of HVDC-VSC is its ability to supply and absorb reactive power, giving stability to the system: VSC converters can also start without electricity supply. IGBTs for converting are electronic semiconductor components with a high switching frequency (2 kHz). This gives lower harmonic levels, hence a reduced need for filters compared to LCC technology. A VSC converter has a maximum capacity of 300-350 MW, so large wind parks (e.g. Bard 1) need more converter stations in parallel. This suggests that for very large power plants (roughly bigger than 1000 MW) HVDC – LCC system is preferable.

3.5.1.4 Comparison among the various transmission systems

The energy loss of AC systems is mainly due to the cables efficiency which can become an issue with long distances because of the reactive power generated in them. Conversely in DC systems the most important energy losses are due to the power conversion, that is independent of cable length. There is a critical transmission distance beyond which HVDC technology becomes convenient in terms of efficiency. This distance is estimated at 55-80 km ([26.][27.]).

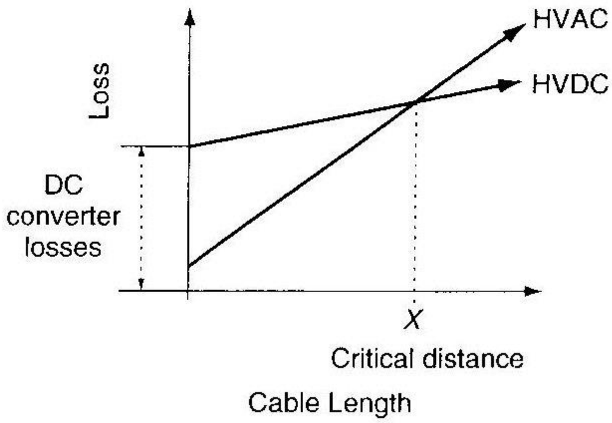


Figure 86 Comparison between HVAC and HVDC in terms of energy loss as a function of the transmission distance. The critical distance X is about 55-80 km ([26.])

Table 5 Comparison among high voltage technologies ([26.])

	HVAC	HVDC LCC	HVDC VSC
Maximum wind farm capacity	200 MW at 150-170 kV 350 MW at 245 kV	1200 MW	Bipolar cable: 600 MW at ±150 kV Converter: 300-350 MW
Maximum distance	200 km at 150-170 kV 100 km at 245 kV	No limits	No limits
Efficiency	Depends on distance	Dipends on converters, less on distance	Slightly lower than LCC
Substations dimension	1/3 of the HVDC ones	The largest	Smaller than LCC ones (e.g. 300 MW: 30 x 40 x 20 m), but higher power requires more substations

3.5.2 The electricity grid connection requirements and technologies

To ensure a safely and efficiently operation, all customers connected to a public electricity network, whether generators or consumers, must comply with agreed technical requirements. Electricity networks rely on generators to provide many of the control functions, and so the technical requirements for generators are necessarily more complex than customers demand.

These technical requirements are often termed 'grid codes', though the term should be used with care, as there are often different codes depending on the voltage level of connection, or the size of the project.

The purpose of these technical requirements is to define the technical characteristics and obligations of generators and the system operator ([28.]). The benefits are:

- Electricity system operators can be confident that their system will be secure no matter which generation projects and technologies are installed
- The amount of project-specific technical negotiation and design is minimised
- Equipment manufacturers can design their equipment in the knowledge that the requirements are clearly defined and will not change without warning or consultation
- Project developers have a wider range of equipment suppliers to choose from
- Equivalent projects are treated equitably
- Different generator technologies are treated equally, as far as is possible.

3.5.2.1 Problems with grid code requirements for wind power

A specific problem today is the diversity of national codes and requirements. Another concern for the industry is the fact that requirements are not formulated precisely enough, leaving room for varying interpretations and lengthy discussions between concerned parties. In some countries, a grid code has been produced specifically for wind power plants. In others, the aim has been to define the requirements as far as possible in a way which is independent of the generator technology. The European Wind Energy Association (EWEA) advocates a Europe-wide harmonisation of requirements, with a code specifically formulated for wind power ([28.]).

Some diversity may be justified because different systems may have different technical requirements due to differences in power mix, interconnection to neighbouring countries and size. However, each country across the globe uses the same constant voltage and constant synchronous frequency system – it is only the physical parameters which are different.

Grid code documents from the different EU countries are not at all homogeneous. Additionally, documents are often not available in English making them inaccessible.

These issues create unnecessary extra costs and require additional efforts from wind turbine designers, manufacturers, developers and operators.

Requirements for the dimensioning, capabilities and behaviour of wind power plants are often not clear, and are not always technically justified or economically sound from the point of view of the system and the consumer.

Historically, requirements have usually been written by the system operator at national level, while the energy regulatory body or government has an overview.

However, in the interests of fairness and efficiency, the process for modifying requirements should be transparent, and should include consultations with generators, system users, equipment suppliers and other concerned parties. The process should also leave sufficient time for implementing modifications. The regulatory process initiated at European level to develop the first European network code on grid connection by ENTSO-E (European Network of Transmission System Operators for Electricity) creates an opportunity for the wind power industry to get thoroughly involved ([28.]).

The wind turbines that are currently available do not yet make full use of all possible control capabilities, for reasons of cost and also because grid codes do not yet take advantage of the full capabilities they could provide. As wind penetration increases, and as network operators gain experience with the new behaviour of their systems, grid codes may become more demanding. However, new technical requirements should be based on an assessment of need, and on the best way to meet that need.

3.5.2.2 An overview of the present grid code requirements for wind power

Technical grid code requirements and related documents vary from one electricity system to another. However, for simplicity, the typical requirements for generators can be grouped as follows ([28.]):

- **Tolerance** - that is, the range of conditions on the electricity system for which wind power plants must continue to operate
- **Control of reactive power**: this often includes requirements to contribute to the control of voltage in the network
- **Control of active power and frequency response**
- **Protective devices**
- **Power quality**
- **Visibility of the power plant in the network**

It is important to note that these requirements are often specified at the Point of Connection (POC) of the wind power plant to the electricity network. In this case, the requirements are placed on the wind power plant. To achieve them the requirements for wind turbines may be different. Often wind turbine manufacturers will only specify the performance of their wind turbines, not the entire wind power plant.

EWEA recommends that for transparency and inter-comparability, all grid codes should specify the requirements to apply at POC. It is also possible to meet some of the requirements by providing additional equipment separate from wind turbines.

Tolerance

The wind power plant must continue to operate between minimum and maximum limits of voltage. Usually this is stated as steady-state quantities, though a wider range may apply for a limited duration.

The wind power plant must also continue to operate between minimum and maximum limits of frequency. Usually there is a range which is continuously applied, and several further more extreme short-term ranges. The operation of a wind turbine in a wider frequency range is not really a complicated task as it mainly involves the thermal overloading of equipment. A possible solution for short-term overload capability consists of oversizing the converters, which in general can be done at reasonable cost. Increased operating temperature may also result in a reduced insulation lifetime. However, since operation at deviating frequency occurs rarely, the effect is negligible and can be reduced by limiting power output at the extremities of the frequency range. Therefore – in general - wind turbines can be made to operate in wider frequency ranges ([28.]).

In systems with relatively high wind penetration, it is common that wind power plants are required to continue to operate during severe system disturbances, during which the voltage can drop to very low levels for very short periods. This is termed fault ride-through (FRT) or low voltage ride-through. A decade back, the TSOs (Transmission System Operators) required all wind turbines to disconnect during faults. Today they demand that wind turbines stay on the grid through these disturbances. Faults are inevitable on any electrical system and can be due to natural causes (e.g. lightning), equipment failure or third party damage. With relatively low transmission circuit impedances, such fault conditions can cause a large transient voltage depression across wide network areas. Conventional large synchronous generators are – in general – expected to trip only if a permanent fault occurs in the circuit to which they are directly connected.

Other generators that are connected to adjacent healthy circuits should remain connected and stable after the faulty circuits are disconnected, otherwise too much generation will be lost in addition to that disconnected by the original fault. Clearly, in this case the power system would be exposed to a loss of generation greater than the current maximum loss it is designed for, with the consequent danger of the system frequency dropping too rapidly and load shedding becoming necessary ([28.]).

The requirements can be complex, and depend on the characteristics of the electricity system. Complying with the requirements may not be easy. It is feasible to use wind turbines which do not themselves comply with the FRT requirements, and meet the FRT requirements by installing additional equipment at the turbines or centrally within the wind power plant which can produce or consume reactive power.

Reactive power and power factor control

Reactive power production and consumption by generators allows the network operator to control voltages throughout their system. The requirements can be stated in a number of ways.

The simplest is fixed power factor. The wind power plant is required to operate at a fixed power factor when generating, often this is 1.0. Often the required accuracy is not stated. The fixed value may be changed occasionally, for example during winter and summer.

Alternatively, the wind power plant can be asked to adjust its reactive power consumption or production in order to control the voltage to a set point. This is usually the voltage at the POC, but other locations may be specified. There may be requirements on the accuracy of control, and on the speed of response. Fast control may be difficult to achieve, depending on the capabilities of the wind power plant SCADA communications system.

Some wind turbine designs are able to provide these functions even when the wind turbine is not generating. This is potentially a very useful function for network operators, but it is not yet a common requirement.

When considering FRT, it is also possible to meet these requirements with central reactive power compensation equipment ([28.]).

Active power control and frequency response

The system operator may add requirements to the code governing the extent to which the generator is capable of actively adjusting the output power. In addition he may require the generator to respond to grid frequency deviations.

For any generator, the ability to control frequency requires controlling a prime mover. Although the wind speed cannot be controlled, the power output of a wind turbine can be controlled by most modern turbines.

With pitch-regulated turbines, it is possible to reduce the output at any moment by pitching the blades. In principle, it is also possible to do this with stall-regulated turbines by shutting down individual turbines within a wind power plant, but this only provides relatively crude control.

The simplest, but most expensive, method is a cap. In this case the wind power plant (or a group of wind plants) is instructed to keep its output below a certain level.

The ability of generators to increase power output in order to support system frequency during an unexpected increase in demand or after a loss of a network element is important for system operation. Therefore, on systems with relatively high wind penetration, there is often a requirement for frequency response or frequency control. Pitch controlled wind turbines are capable of such system support only when they are set in advance at a level below the rated output and, of course, if wind is available. This allows them to provide primary and secondary frequency control. This can take many forms, but the basic principle is that, when instructed, the wind power plant reduces its output power by a few percent, and then adjusts its output power in response to the system frequency. By increasing power when frequency is low or decreasing when frequency is high, the wind power plant provides a contribution to controlling the system frequency ([28.]).

The problem associated with this type of network assistance from wind turbines is a reduced output and hence loss of income.

Protective devices

Protective devices such as relays, fuses and circuit breakers are required in order to protect the wind power plant and the network from electrical faults. Careful co-ordination may be required, in order to ensure that all conceivable faults are dealt with safely and with the minimum disconnection of non-faulty equipment ([28.]).

Power quality

This term covers several separate issues that determine the impact of wind turbines on the voltage quality of an electric power network. It applies in principle both to transmission and distribution networks, but is far more essential for the latter which are more susceptible to voltage fluctuations on the generation side. The relevant parameters are active and reactive power, including maximum value, voltage fluctuations (flicker), number of switching operations (and resulting voltage variations), harmonic currents and related quantities ([28.]).

The standard for characterising the power quality of wind turbines and for the measurement of the related quantities is IEC 61400-21. The application of this standard enables a careful evaluation of the impact of wind power plants on the voltage quality in electrical networks. Instead of applying simplified rules which would be prohibitive for wind power, analysis of IEC 61400-21 methods is recommended in order to carry out the following:

- Load flow analysis to assess whether slow voltage variations remain within acceptable limits
- Measurements and comparison with applicable limits of maximum flicker emission which can be caused by wind turbines starting or stopping, or in continuous operation
- Assessment of possible voltage dips due to wind turbine start-up, stops or by energisation of transformers
- Estimation of maximum harmonic current and comparison with applicable limits.

Visibility

In a power system with large contributions from decentralised plants, it is essential for the system operator to obtain on-line information about the actual operational conditions at the decentralised plants. Access to such information can, for example, be critical during network faults when fast decisions have to be made to reschedule generators and switch network elements. For this purpose, agreements are made between the system operator and the wind plant operators on communicating signals such as active and reactive power, technical availability and other relevant status signals. On-line information about wind plants can also be necessary for system operation for the purpose of short-term forecasting of the output of wind plants in a region ([28.]).

Future developments

As noted above, technical requirements may well become more onerous as wind power penetration levels will increase in the future.

One possible new requirement is for an inertia function. The spinning inertias in conventional power plants provide considerable benefits to the power system by acting as a flywheel, and thereby reducing the short-term effects of imbalances of supply and demand. Variable speed wind turbines have no such equivalent effect, but in principle their control systems could provide a function which mimics the effect of inertia ([28.]).

The challenges of floating offshore wind farms grid connection from substation to shore, do not significantly differ from those for fixed foundations.

The distance from the shore and the availability of networks at the point of connection remain a potential bottleneck. However, as far as cable technology is concerned, the dynamic section of the cables is an important issue. The motion induced by the turbine and the non-fixed foundation can put additional loads on the cables.

In water depths of more than 100m, the array cable layout could also pose technical problems. With an array cable laid on the seabed or submerged at around 50m, a longer cable would be needed, which could lead to the cable moving. Studies of dynamic response of the cables and evaluation of cost effective solutions need to be developed.

While more research is required on mooring and anchoring systems, the deep offshore wind industry should be able to benefit from the experience gained in the oil and gas sector, where these systems have been used for many years. Increased exchange of knowledge and cooperation with the oil and gas industry would help develop deep offshore faster and more cost effectively.

In conclusion, deep offshore designs are still in their infancy. Commercialisation can be expected over the next five to six years but much innovation is still required to ensure design reliability and commercial viability.

3.5.3 Power Control Systems

Wind turbines are designed to produce electrical energy as cheap as possible during its lifetime. They are generally designed to yield maximum output at wind speeds around 15 m/s. As it described above, in case of strong winds, to avoid damaging the turbine, the excess energy of the wind is discharged. The cost of the investment would be very high to dimension the system to catch strong winds that are quite rare. Therefore turbines are not designed to maximise their output at stronger winds but they have a built in device to control the power output.

There are basically three types of <u>power control system</u> as described hereafter.

The <u>pitch controlled</u> wind turbine checks the power output several times per second. When it becomes too high, it turns the rotor blades slightly out of the wind and puts them back into the wind when it drops again.

The <u>passive stall controlled</u> wind turbine has the profile of the blade aerodynamically designed to ensure that the moment the wind speed becomes too high, it creates turbulence on the side of the rotor blade not facing the wind thus preventing the lifting force of the rotor blade from acting on the rotor. Around two thirds of the wind turbines currently installed in the world are stall controlled machines.

The <u>active stall power control</u> mechanism has pitchable blades. At low wind speeds the machine is programmed to pitch the blades like a pitch controlled machine in order to get a reasonably large torque. When the generator is about to be overloaded, the machine will pitch its blades in the opposite direction from what a pitch controlled machine does. The power output is more accurately controlled and the machine can run almost exactly at rated power at all high wind speeds. The disadvantage is that this system is quite expensive.

The rotor of a wind turbine should be perpendicular to the wind. If that does not happen the rotor area will catch a lower share of the energy in the wind and the part of the rotor that is closest to the source direction of the wind will be subject to a larger force (bending torque) than the rest of the rotor. For each turn of the rotor, the blades will be bending back and forth and therefore they will be subject to larger fatigue loads. The <u>yaw control system</u> is activated by the electronic controller which several times per second checks the position of the wind vane on the turbine, whenever it is running.

The rotor blades, before installation, are subject to a static and dynamic test to verify their ability to withstand fatigue from repeated bending more than five million times.

The current generated by the wind turbine generator is channelled by electrical cables from the hub down through the tower. If the turbine by accident keeps yawing in the same direction for a long time the cables will become more and more twisted. A cable twist counter is controlling when it is time to untwist the cables.

If the shaft of the turbine starts shaking or the oil temperature in the gearbox is exceeding the limits, a vibration and temperature sensor will switch the turbine off.

The fail safe brake mechanisms is an overspeed protection system that stops the turbine by braking the rotation of the rotor when the same will start to accelerate rapidly, i.e. in case of sudden disconnection from the electrical grid.

Modern turbines normally use an aerodynamic braking system, utilizing a mechanical brake only as a backup system to the aerodynamic one and as a parking brake in case of maintenance works. The brake mechanism offers a very gentle way of braking the turbine without any major stress, tear and wear on the tower and the machinery.

3.5.4 Structural Health Monitoring (SHM) systems

A very critical issue for very large offshore wind turbines is the structural integrity of the rotor blades, tower and floater or the foundation respectively, and their remote maintenance. On the one hand, the wind turbines of the future will be much bigger than today. Especially the rotor blades which will have a length of 90 m and more are very critical. The probability of structural failure is much higher than with smaller blades. Additional to that, the environmental conditions on the sea are very harsh, that means the loads onto blades and tower are much higher. On the other hand, the accessibility of an offshore wind turbine is restricted due to sea and weather conditions and the availability of supply vessels. Some challenges are harsh offshore environment, underwater measurements, a very complex floating structure with varying loads and boundary conditions, a rotating system, interaction of the mechanical dynamics of floating turbine with aero-elasticity and control commands, interaction between different structural components, etc.

Therefore, integrated structural health and condition monitoring is a prerequisite of complex remote maintenance strategies for structural parts of a wind energy converter. Structural Health Monitoring, condition-dependent and predictive maintenance combined with long-term planning of repair measures is the key to ensuring the economic viability of very large offshore turbines. Additional to the health monitoring the measurement of the dynamic behaviour of floating wind turbines is of great importance for research purposes ([78.]).

In a European research project HiPRwind a floating wind turbine will be monitored. SHM is a main research topic at the floater which will be situated off the coast of Spain. The intension of SHM is not only to indicate an upcoming damage, but additionally to deliver information about the position of damage and its extent. To monitor local effects in the whole blade a sensor network is necessary covering the whole structure.

SHM is a monitoring system with 3 different measuring techniques consisting of a combination of acoustic emission, acousto ultrasonics and the vibro-mechanic method of operational modal analysis (OMA). While the local monitoring is based on guided elastic waves the global measurement is working with the measurement of accelerations.

Acoustic Emission, AE, is a passive technique. Bursts of fibres, cracking of glue and inter-laminar friction cause acoustic emission. The signals are received by piezo transducers. By means of triangulation a localisation of such acoustic events is possible. A summation of acoustic effects over the life time of a rotor blade shows the regions with highest structural changes (Figure 87).

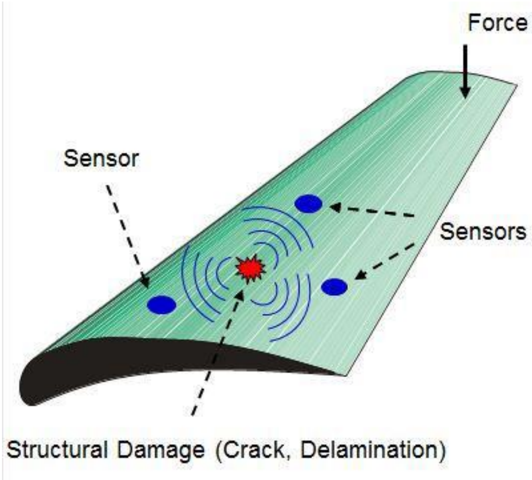


Figure 87 Functional principle of acoustic emission

Acousto Ultrasonics, AU, as an active principle, using piezo transducer as emitter and receiver of guided waves. When damage occurs between emitter and receiver the transfer function of the signals will be changed, that means the signal received differs from the one emitted (Figure 88).

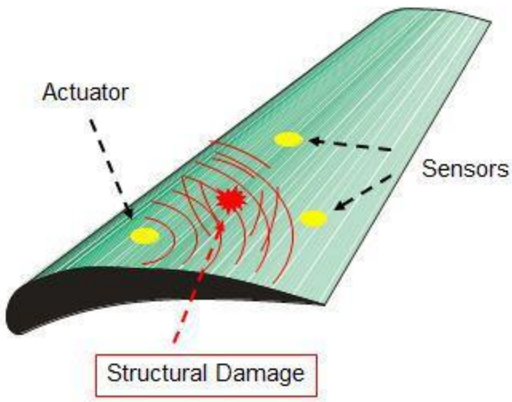


Figure 88 Functional principle of acousto ultrasonics

The main task of global monitoring is to keep the load bearing capacity of the rotor blade under surveillance. By means of an operational modal analysis, OMA, natural frequencies, mode shapes and damping are measured.

The modal parameters of a blade are changing with temperature, wind speed, pitch angle, etc. Additionally, there are different sources of blade excitation, e. g. by wind, gusts, tower blade passage, etc. which have to be considered in the context of OMA. In order to compensate these influences on the OMA results pattern recognition techniques are necessary. Therefore, all important combinations of the above-mentioned parameters are modelled together with the changes of extracted dynamical properties (features) of the blade. This correlation model between dynamics and environmental and operational conditions (EOC) built during the healthy state of the blade represents the reference state of this structural component.

During the whole life time of the blade the extracted features are compared to the reference model. Differences between the features and their model are evaluated in a statistical way. If the differences are significant from statistical point of view, blade damage can be assumed. Without using pattern recognition techniques for EOC compensation no damage detection is possible, also effects of the large damages will be masked by effects of EOC changes on the extracted features.

Figure 89 represents results of OMA after EOC compensation. The change of the colour from green to red signals the proceeding degradation of the blade (Figure 89, top). Due to structural degradation repair measures should be started (Figure 89, bottom).

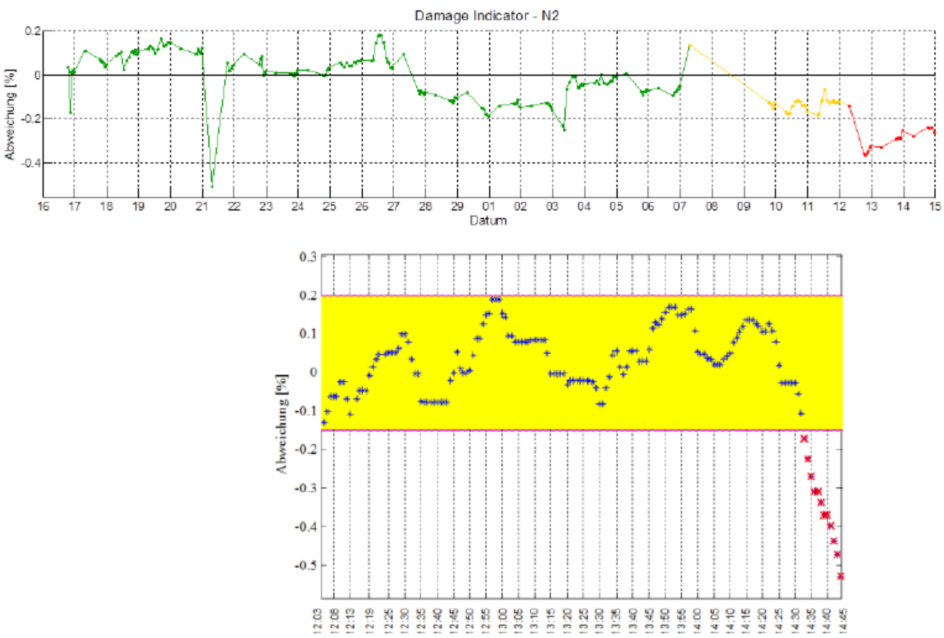


Figure 89 Objective of data processing is a clear indication of starting damage processes to allow for a stop right before failure

As mentioned above, in a European R&D-project HiPRwind the SHM-system for rotor blades will be further developed and expanded to the whole structure including floater, tower, blades and nacelle (Figure 90).

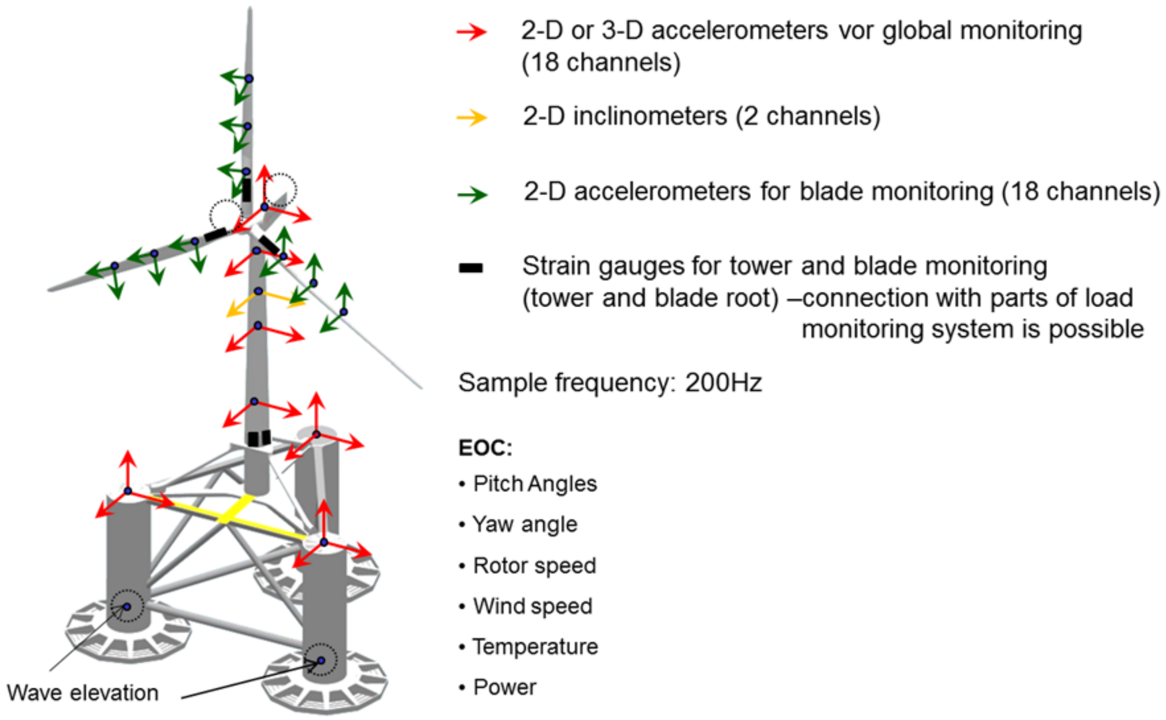


Figure 90 Instrumentation plan of HiPRwind floater

The challenge of this project HiPRwind is among others is the very harsh offshore environment and the interpretation of the dynamic behaviour of the complex structure.

3.5.5 Electricity storage and transformation systems

All electricity generation is intermittent because of interruptions for maintenance (usually planned) or breakdown (unpredictable). The generation of electricity from most of the renewable resources is even more variable because generation depends on external factors such as the availability of wind for wind generation or the amount of sunlight for solar panels. It is therefore required a certain amount of reserve capacity to ensure a reliable supply.

At present the variability of renewables does not affect significantly the network because its contribution is fairly low. But if the global target set to reduce greenhouse gas emissions by

50% by year 2050, compared with 1990 levels, is to be met, a much higher percentage of renewables is required to “decarbonise” the electricity production. Therefore the system will require much more reserve capacity to maintain a good balance between demand and supply as wel as to ensure grid stability and a reliable electricity supply.

Electricity storage could be the answer and appears to be the only efficient and environmentally friendly way to guarantee a reliable supply of electricity throughout the day. Storage units can be placed next to wind farms. The storage unit absorbs excess power during periods of strong wind and uses it to supplement the power flow during periods of calm. This increases the generation reliability, allowing it to be sold for a higher price.

Storage facilities can be modular, relatively quick to build and readily expandable. However, the initial costs are high, leading to long payback times (over 10 years) ([29.]).

The efficiency and cost-competitiveness of renewable electricity generation could be significantly improved by the availability of low-cost, high-capacity storage. Electricity storage has a large variety of potential uses in a modern electricity network depending on where it is placed in the network, the amount of energy it can store and the rate at which it can deliver that energy. Large scale, megawatt-level electricity storage systems, or multiple, smaller distributed storage systems, could significantly reduce transmission system congestion, manage peak loads and increase the reliability of the overall electric grid.

There are currently several promising energy storage technologies at varying stages of maturity ([30.]).

The oldest form of large-scale, high-energy, high-power electricity storage is the Pumped hydroelectricity storage. During periods of low demand, the electricity in excess is utilized to pump water from a reservoir placed at a lower level to another at high elevation. When demand for power is high, stored water is allowed to flow from the upper reservoir back to the lower through hydroelectric turbines to generate electricity. The system allows the recovery of about 75% of the electricity used.

The Compressed Air Energy Storage is based on the same principles of the pumped storage and in the same way is capable of providing significant reserve services. The system uses the available cheap electricity during periods of low demand to power high efficiency compressors to store air at high pressure into underground reservoirs. When the commercial demand for power is high, the stored air will power a turbine connected to electric generators that provide electrical power to the grid.

Both systems can start generating electricity almost instantly when it is requested and offer storage of large amounts of potential electrical power. However for large scale utilization they are subject to some limitations such as suitable geographic siting. The compressed air storage in addition to large scale installations can be adapted for small scale operations by making use of high pressure tanks or pipes.

There are many battery storage technologies available (lead-acid, lithium-ion, sodium-sulphur and sodium nickel-chloride designs). Thanks to their portability, ease of use and variable storage capacity they can cover a wide range of energy storage applications. A Sodium-sulphur set of batteries 34MW capacity has been installed at a wind farm in Japan. Batteries can be used to help balance the electricity network as well as engaging in energy arbitrage (buy and store at cheap rates and sell to the grid at peak times). However batteries are very expensive and may have short lifetimes.

Flywheels and Supercapacitors are low-energy, high-power storage systems. They can be discharged instantaneously with high power output over short time periods. Due to their low energy storage potential these technologies are best utilized for applications such as voltage and frequency stabilization but do not have applications at the transmission level. Their commercial applications are primarily limited by the required materials properties and relevant cost.

Similarly Electrochemical Capacitors are suitable for fast-response, short-duration applications, excellent for stabilizing voltage and frequency. Notwithstanding the several advantages including a temperature-independent response, low maintenance and long projected lifetimes (up to 20 years), this technology is still limited by its high cost.

Other technologies are also at different stages of maturity. The availability of a reliable and cheap energy storage system will definitely provide a boost to the development of wind power generation allowing companies to manage supply and demand more effectively by introducing a high degree of flexibility and a quick response to the demand of supply in the electrical network without the expense of high carbon and cost. It still remains the economic issue for the deployment of storage linked to the high capital costs as opposed to conventional fossil-fuel reserves. But as the proportion of power generated by wind increases, storage may become economically viable.

Summing up, the technologies such as pumped hydro or compressed air energy storage are suitable for large-scale energy storage needs but limited to specific sites where reservoirs or caverns are available. On the other end the traditional technologies such as batteries, flywheels, capacitors etc. capture, store and discharge electricity at a single location, but offer a very limited storage capacity.

Figure 91 shows the contribution of the different storage systems in relation to their storage capacity and the availability of suitable sites. To boost renewable energy contribution to the total energy demand are required large storage facilities available where they are needed ([59.]).

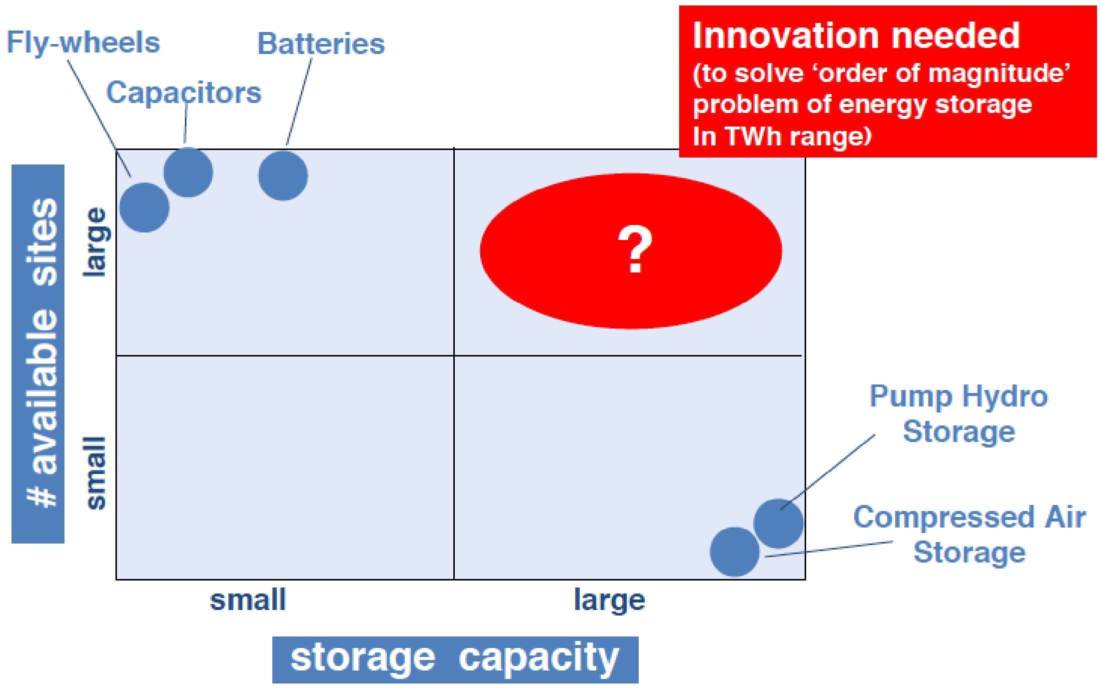


Figure 91 Electric energy storage: technology assessment

Figure 92 shows the contribution of each technology as storage capacity in terms of volumetric energy storage density in kWh/m^3 ([59.]).

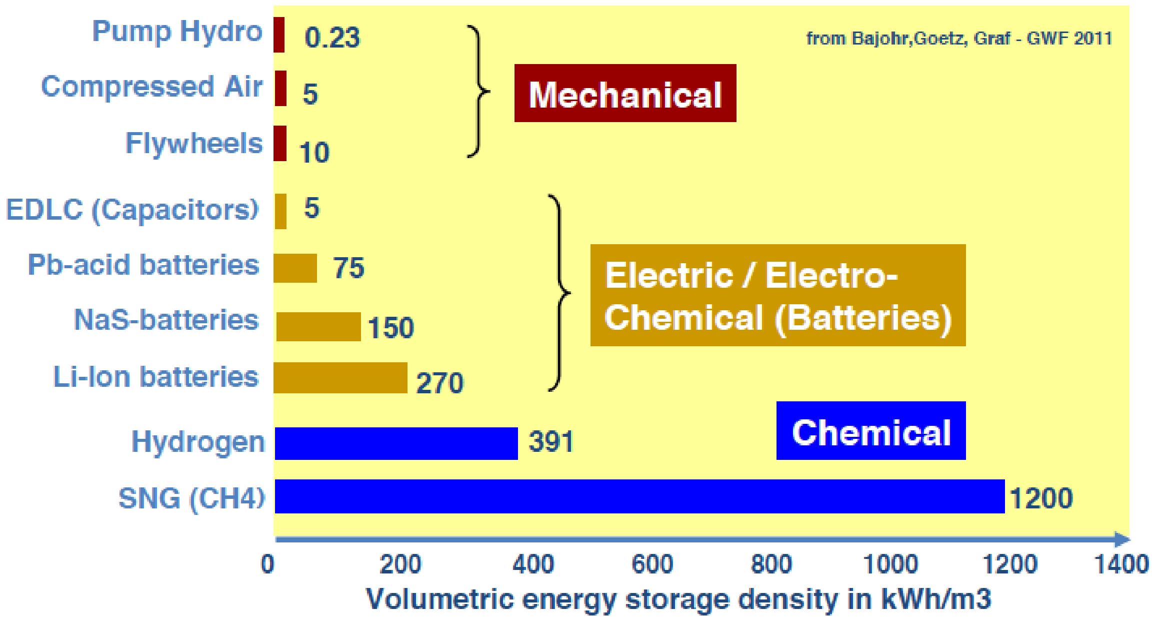


Figure 92 Electric energy storage densities

Interesting solutions to mitigating the intermittency of renewable electric energy can be offered by the “Power to Gas” technologies (P2G) in association with the highly developed infrastructure of the natural gas industry.

In fact P2G technology produces a chemical energy carrier as hydrogen or SNG (Synthetic Natural Gas) that offers the highest energy storage density that can be injected in the natural gas grid.

The availability of tens of thousand of kilometers of pipes in Europe represents a storage capacity of some billions of cubic meters of gas and with a mix ratio of 10% of H2 or SNG injected some TWh of total electric energy storage capacity are available ([59.]). This huge energy storage potential of the natural gas network is probably destined to play an important role as “enabler” for a high share of renewable energy.

Natural gas Infrastructure	Transport Network (km)	UGStorage (In Mrd m3)	Total electric energy storage capacity (in form of H2 at 10% H2 in NG)
Italy	33.000 km	14.9	4.6 TWh
Germany	33.500 km	20.4	6.4 TWh
UK	29.600 km	4.4	1.4 TWh
France	37.600 km	12.6	3.9 TWh

Figure 93 Natural gas network and electric energy storage capacity

‘Power to Gas’ technologies and a convergence of the power and natural infrastructure might become a credible option for mitigating the problems of intermittency of renewable energy.

The scheme below gives a schematic idea of the different technologies under development.

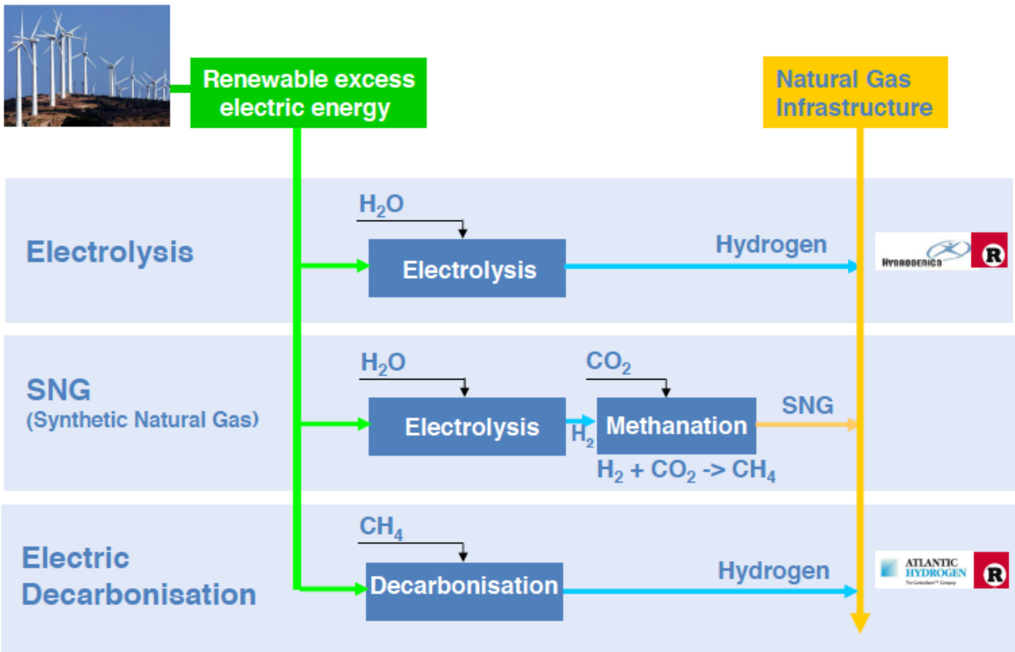


Figure 94 Power to gas: developing technologies

The technology based on electrolysis is basically centered on the electrolyzer ([60.]). The surplus energy from a wind farm is converted to hydrogen by splitting water molecules (H2O) into hydrogen (H2) and oxygen (O2) using electricity. The hydrogen and oxygen are produced in gaseous status from the electrolyzer without any carbon emissions. The hydrogen is then compressed, metered and injected into the existing natural gas infrastructure.

The system can be deployed at sites on the power grid where there is congestion, providing a dynamic and highly effective adjustment to the variations in renewable generation output. In fact the Power-to-Gas solution leverages the advantages of the natural gas system providing both the transportation of energy through the existing natural gas pipeline network and the storage in its associated underground storage facilities. The advantages of the utilization of the natural gas system are that the storage of energy is no more restricted to the site of the generation and it offers an alternative to the electrical transmission grid alleviating the network congestion.

A first industrial application of the technology based on electrolysis was recently inaugurated in Falkenhagen in eastern Germany in the month of August 2013 ([61.]). E.ON in partnership with Swissgas AG built a power-to-gas (P2G) unit that uses wind power to run electrolysis equipment that transforms water into hydrogen that is injected into the regional gas transmission system.

The hydrogen becoming part of the natural gas mix can be dispatched to the usual destinations, including electric power generation.

The unit has a capacity of two megawatts and can produce 360 cubic meters of hydrogen per hour. This pilot project uses proven technology and therefore is well suited for gathering technical and regulatory experience in the construction and operation of P2G storage units ([62.]).

Figure 95 E.On Power-to-gas unit inaugurated in Falkenhagen (Germany)

This experience is one of the first aimed at demonstrating that surplus energy can be stored in the gas pipeline system in order to help balance supply against demand. It will represent an important step toward making P2G technology ready for the mass market.

Another option is to produce substitute natural gas through a methanation process. For example, hydrogen can be used to enhance the energy content and utility of existing biogas plants by converting the carbon dioxide content (typically 35—40%) to biomethane.

To meet the target of replacing the fossil fuels with renewable resources is a challenging task represented by the need to continuously maintain the balance between supply and demand through an optimal management of the energy system including operational, commercial and financial aspects of the different energy sectors involved that should be considered as a unique whole system ([60.]).

A first step towards improving the overall efficiency of the energy system is the evolution towards a smart gas grid system with the integration of Advanced Metering Infrastructures. It will offer ability to deal with non-conventional gases (i.e. hydrogen, biomethane, etc.), control to meet the time-varying gas demand and to interact with the smart power grid, thus becoming a fundamental part of a smart energy system ([60.]).

3.6 LCA in Wind Energy

The LCA approach provides a conceptual framework for a detailed and comprehensive comparative evaluation of environmental impacts as important sustainability indicators. Recently, several LCAs have been conducted to evaluate the environmental impact of wind energy ([31.]). Different studies may use different assumptions and methodologies, and this could produce important discrepancies in the results among them. However, the comparison with other sources of energy generation can provide a clear picture about the environmental comparative performance of wind energy.

An LCA considers not only the direct emissions from wind farm construction, operation and dismantling, but also the environmental burdens and resources requirement associated with the entire lifetime of all relevant upstream and downstream processes within the energy chain. Furthermore, an LCA permits quantifying the contribution of the different life stages of a wind farm to the priority environmental problems.

Wind energy LCAs are usually divided into five phases:

1. **Construction** comprises the raw material production (concrete, aluminium, steel, glass fibre and so on) needed to manufacture the tower, nacelle, hub, blades, foundations and grid connection cables.
2. **On-site erection and assembling** includes the work of erecting the wind turbine. This stage used to be included in the construction or transport phases.
3. **Transport** takes into account the transportation systems needed to provide the raw materials to produce the different components of the wind turbine, the transport of turbine components to the wind farm site and transport during operation.
4. **Operation** is related to the maintenance of the turbines, including oil changes, lubrication and transport for maintenance, usually by truck in an onshore scheme.
5. **Dismantling**: once the wind turbine is out of service, the works of dismantling the turbines and the transportation (by truck) from the erection area to the final disposal site; the current scenario includes recycling some components, depositing inert components in landfills and recovering other material such as lubricant oil.

Within the framework of the ECLIPSE project - "Environmental and ecological life-cycle inventories for present and future power systems in Europe", several LCAs of different wind farm configurations were performed. The technologies studied in ECLIPSE were chosen in order to be representative of the most widely used wind turbines.

Nevertheless, a wide range of the existing technological choices were studied:

- Four different sizes of wind turbines: 600 kW (used in turbulent wind conditions), 1500kW, 2500 kW and 4500 kW (at the prototype stage);
- A configuration with a gearbox and a direct drive configuration, which might be developed in the offshore context;
- Two different kinds of towers: tubular or lattice;
- Different choices of foundations, most specifically in the offshore context.

In Figure 96, the contribution of different life cycle phases to the emissions is depicted. In an offshore context, the contribution of the construction phase is even more important, accounting for around 85 per cent of the emissions and hence of the impacts.

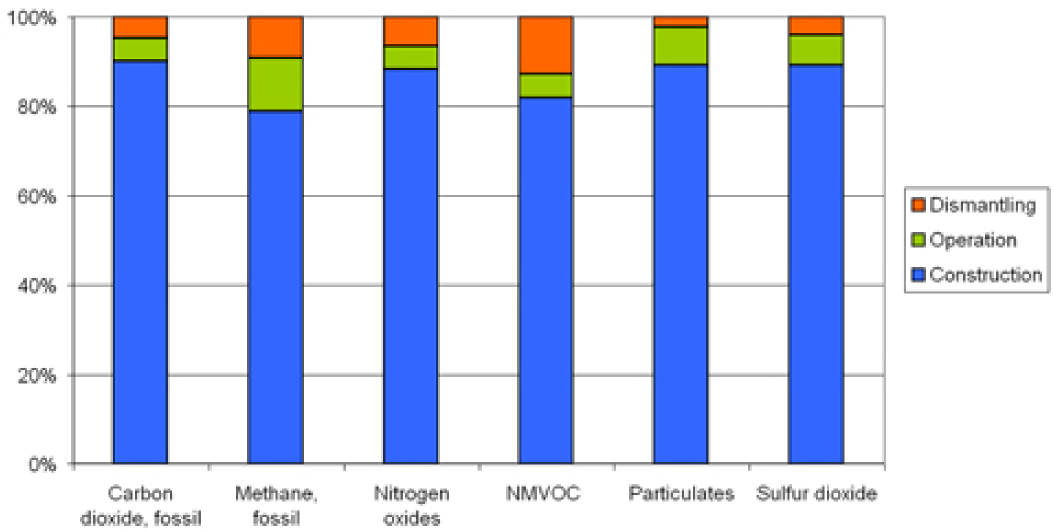


Figure 96 Contribution of the Different Life Cycle Phases of an Offshore Wind Farm to the Relevant Emissions (elaboration using ECLIPSE results)

Within the construction stage, Figure 97 shows the contribution of the different components. Important items in the environmental impacts of the construction phase of an offshore wind farm are the nacelle and the foundations followed by the tower. The rotor blades are not found to play an important part. Emissions from transport activities during construction phase are quite relevant in the case of NOx and NMVOC (Non-methane volatile organic compounds) emissions.

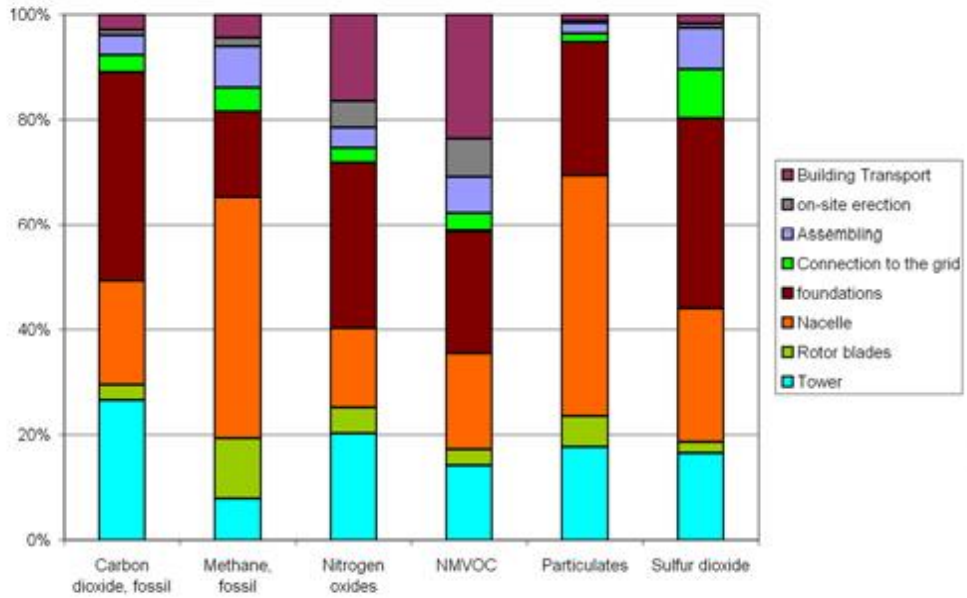


Figure 97 Contribution of the Components of the Construction Phase to the Different Emissions (elaboration using ECLIPSE results)

4 Technologies and Materials to realize off-shore wind turbines components

4.1 Blades

The wind industry is a major user of composites, mainly in blade manufacture [33.].

Advances in blade technology will help to reduce costs over the next decade and enable the manufacture of the longer blades that will be needed for the next generation of turbines.

In Figure 98 is shown a breakdown of material usage in a 500MW offshore wind farm with 100 turbines. Approximately 6.5% of an offshore wind farm is made of composites (see Figure 98) and most of the composite materials can be found in the nacelle and in the rotor blades ([32.]).

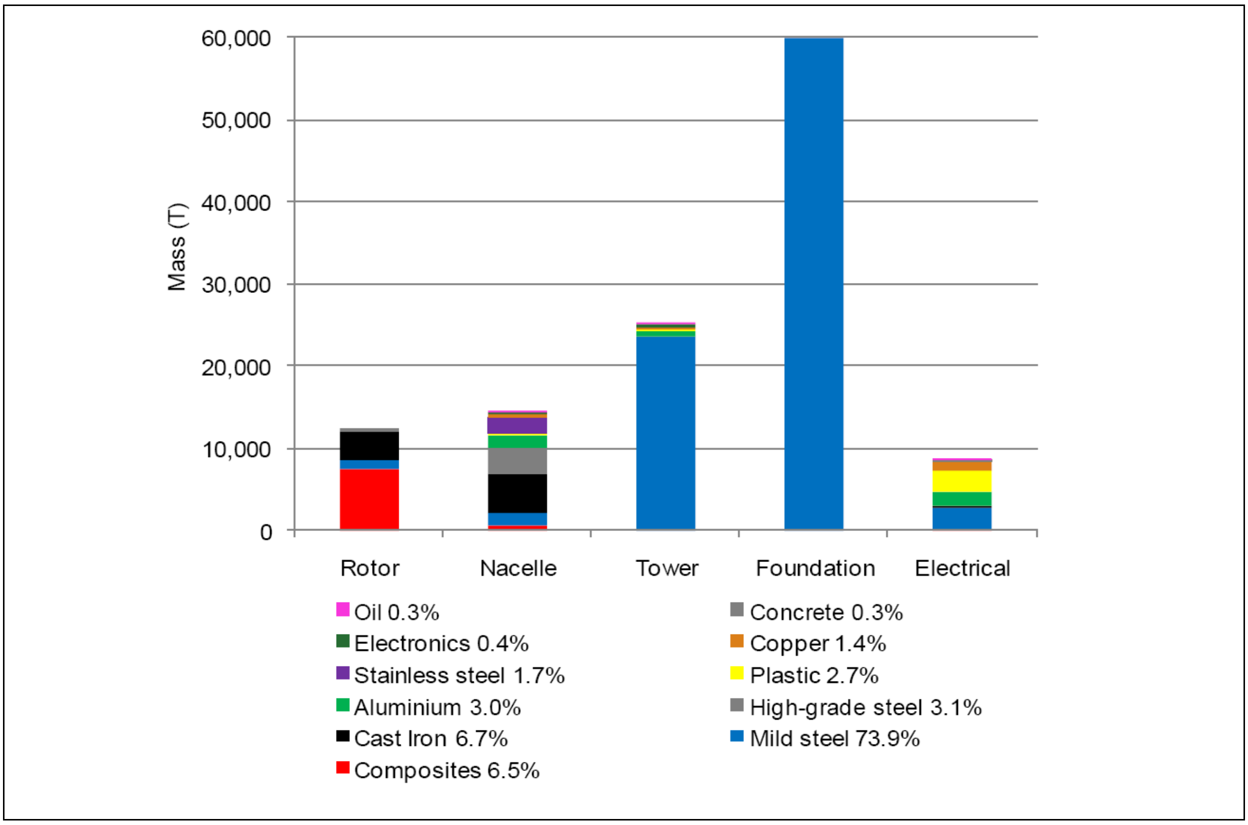


Figure 98 Indicative breakdown of material usage in a 500MW offshore wind farm with 100 turbines

To date, most turbine blades have been made in a single piece and lengthwise to avoid the technical challenges of making robust joints without significant increases in weight. Sectional blades have been used successfully onshore by Enercon to overcome the limitations of transporting blades. It is expected that offshore blades will, where possible, be made at coastal

facilities to avoid the need for onshore transportation and, in general, the industry will continue to manufacture blades in a single section. The UK company Blade Dynamics, based on the Isle of Wight, has plans to introduce a two-section design for assembly on site that will be able to be scaled up to more than 90m long for the offshore market.

The current generation of large turbines all have three blades. Turbines with three blades capture slightly more energy than those with two but the cost of the energy benefit is marginal at best. Designs with two blades have been deployed on land but they have an inherently higher tip speed, making them noisier, and people tend to find them more visually intrusive. These considerations are less important far from shore. Turbines for the large wind market are almost all upwind designs (with the rotor upwind of the tower).

Offshore, noise and visual intrusion are less of a constraint and the Dutch company 2-B Energy has been an early mover towards two-bladed, downwind turbines, having a 6MW model in development. Other players are taking advantage of decreased noise constraints by adopting the more conservative approach of increasing the tip speed of the blades by allowing their conventional rotor to turn faster without making a change to the turbine concept.

While all established large wind turbine manufacturers are committed at present to horizontal axis turbines, there is some interest in developing large vertical axis turbines, especially for eventual use at 10MW or larger.

Although the choice of blade technology varies between manufacturers and turbine models, composites are used as the basis of all blades.

Hereafter are described the technologies used to make blades with particular reference to the materials, design and certification and manufacturing.

4.1.1 Materials

The primary technology drivers ([32.]) for material use are:

- **Cost**. Materials make up more than 50 per cent of the cost of the blade, so price has a significant impact on the commercial and technology decisions to be considered for blades design and construction. Labour and consumables account for about 30 per cent of blade costs and tooling and factory depreciation costs are usually 20 per cent.
- **Fatigue resistance**. Blades are exposed to a high, cyclical and variable load regime under which the materials must last for 20 years in an offshore environment with minimal or no maintenance.
- **Mass**. As turbines get larger, mass becomes a significant driver for material choice. This is because self weight is a design driver for large blades and mass reduction in blades can lead to reduced costs for the turbine and foundations.

- **Ultimate tensile strength**. Blades need to withstand a range of operational and storm conditions. Materials that are stronger enable the design of lighter blades.
- **Stiffness**. The potential for the blade to strike the tower is an issue which drives the need for stiffer structures as the length of blades increases. In addition, keeping natural frequencies away from driving frequencies is critical.
- **Consistency**. In order to optimise blade design, material properties must be well understood. There is therefore benefit in avoiding materials with variations in their properties.

Composite materials are formed from two major components: the fiber and the matrix. The fiber provides the key mechanical properties and the matrix, a polymeric material, supports and holds in place the fibers. Different properties are achieved by altering the fiber and matrix materials, layout and combination. Some examples of the different elements of the blade are shown in Figure 99.

Additional materials used within the composite structure of the blade include:

- Sandwich core materials, used to stabilise the structural layers and carry the shear loading on the structure
- Surface finish coatings, which are needed to protect the composite from erosion and UV light, and
- Adhesives, used to bond together the composite subcomponents.

In Table 6 the different types of blade material are reported.

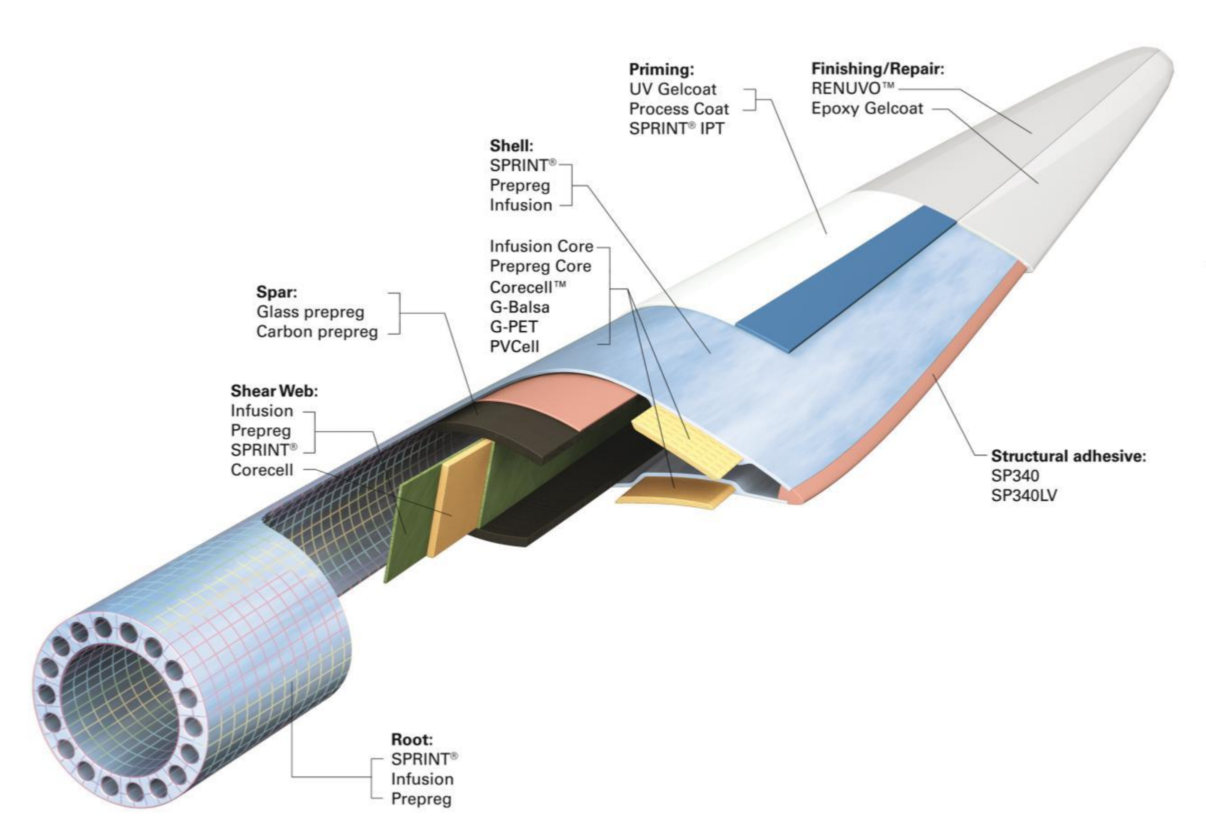


Figure 99 Composite materials in a turbine blade

Table 6 Types of blade material

Technology	**Resin infusion**	**Prepreg**	**Integral blade vacuum infusion**
Fibre	Glass or carbon	Glass or carbon	Glass or carbon
Resin	Polyester or epoxy	Epoxy (pre-impregnated into fibre)	Epoxy
Sandwich core	Balsa or polymer foam	Balsa or polymer foam	Balsa or polymer foam
Surface finish	In mould gelcoat when polyester is used; paint when epoxy is used	Sprayed on polyurethane paint	Sprayed on polyurethane paint
Assembling of blade shells and web	Bonding with structural adhesive	Bonding with structural adhesive	No bonding zones
Company example	LM Wind Power, Areva, REpower	Vestas Wind Systems, Gamesa	Siemens Wind Power

4.1.1.1 Fibers

The most commonly used structural material in wind turbine blades is glass fibre (see Figure 100). Carbon fibre is also used in approximately one quarter of wind turbine blades being installed worldwide and, where it is used, carbon fibre forms about 15 per cent of blade mass.

A range of glass fibre grades are available. E glass is extensively used and each glass fabric-resin combination has to be tested and qualified before it is specified in a blade design. As wind blades grow in length, higher demands are placed on the reinforcements. A new generation of glass fibres is entering the market and is being evaluated by blade manufacturers. These materials provide a higher modulus (stiffness) and are moving to fill the gap in performance between carbon and E glass. They may provide a more cost-effective alternative to carbon in developing blades over 70m long. Two options are R glass and S glass. While the properties of S glass are superior to R glass, it is more expensive and requires significant investment on the part of manufacturers. R glass may therefore prove to be the favoured material for the next generation of offshore blades.

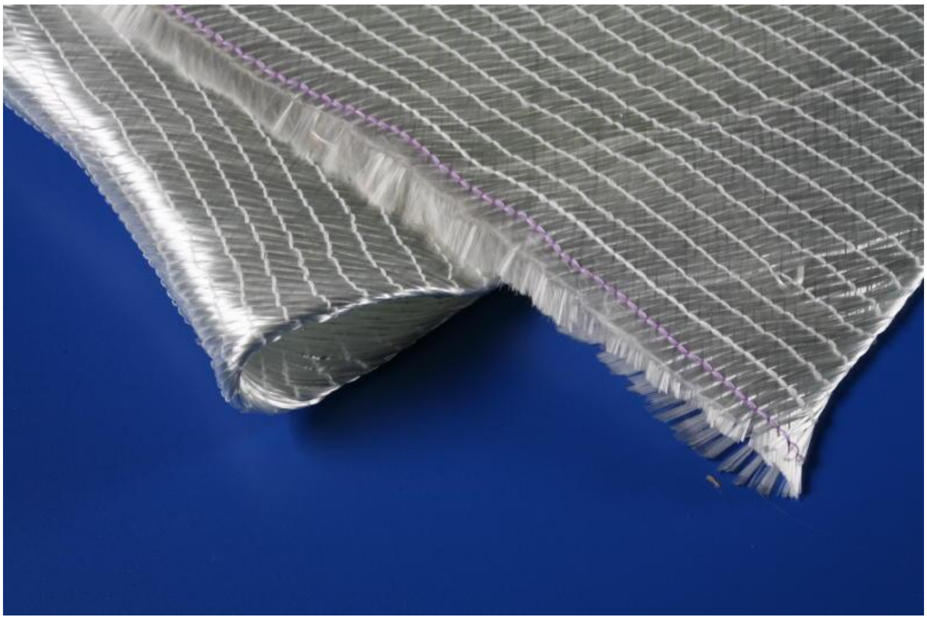


Figure 100 Woven glass fibre

Vestas Wind Systems and Gamesa are the dominant users of carbon fibre in wind turbine blades. Although it is significantly more expensive, carbon fibre composites can be a financially viable alternative to glass fibre composites as they have higher strength and stiffness, so less material is required for a given application and blades are lighter.

Carbon fibre composites have typically been used by pre-impregnating them with an epoxy resin. The fabric can either be completely impregnated with resin (called prepreg, see Figure 101) or have a layer of resin on one side (semipreg). In both of these forms, the resin and hardener of the epoxy resin are premixed, which means the material must be stored in a freezer to prevent curing taking place.

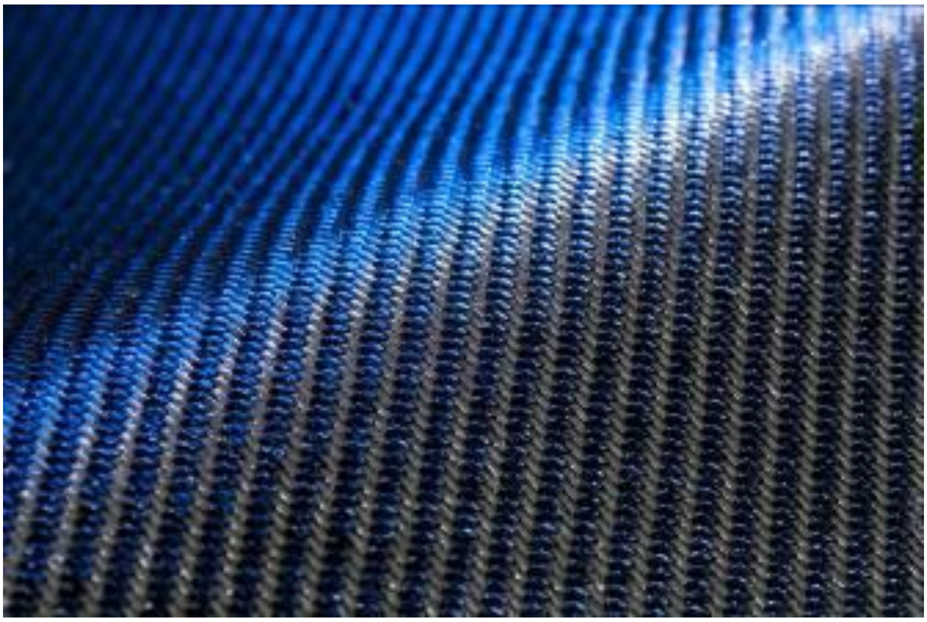


Figure 101 Carbon fibre prepreg

4.1.1.2 Matrixes

The resin used in the blade manufacturing are the following:

- epoxy resin
- polyester resin.

The majority of blade manufacturers, with the significant exception of LM Wind Power, use epoxy resin and it is anticipated that this technology will account for most offshore blades up to 2020. Epoxy is a thermosetting polymer with better mechanical properties and environmental resistance than polyester, although it is more expensive. Epoxy resin is produced by mixing two parts, the resin and the hardener, which undergo a cross-linking process causing the material cure. The final properties of the resin are defined by the mixture ratio of resin and hardener and by controlling the curing process. Some formulations require heating during the cure process, whereas others simply require time at ambient temperature. Epoxy, like most thermosetting resins, cures exothermically. Care must therefore be taken during the curing process when applying heat or in making thick parts to avoid charring or even ignition. The fibre÷epoxy resin ratio is generally 60÷40.

Polyester has been used extensively in smaller blades up to 25m long and by LM Wind Power on blades up to 61.5m. Polyester is an unsaturated, thermosetting polymer which is cheaper than epoxy resin but has inferior mechanical and environmental properties. It is commonly used in the marine vessel industry. Polyester resins need a catalyst rather than a hardener to initiate cure, which makes the mixing process less critical.

Polyester resin can also include many additives such as pigments, UV stabilisers, fillers, and fire or chemical resistant substances. Styrene is added to reduce the viscosity of the resin, making it flow better. Styrene plays a vital role in the curing process of the product but create environmental issues during processing as well as significant shrinkage of parts on cure. Polyester does not need to be heated to activate the process and achieve its full strength, so mould tooling tends to be simpler and cheaper and energy costs of production are lower. It is typically used in a 50÷50 fibre÷resin ratio.

A number of matrix material and structural material combinations are used in the manufacture of wind turbines blades (see Table 7).

Table 7 Combinations of structural materials used in large wind turbine blades

	Polyester resin	Epoxy resin
Glass fibre	• Traditionally used in boat manufacture • Cost-effective and proven • Less strong than the glass and epoxy combination • Most commonly moulded using infusion	• The most widely used structural material combination for blades • Many players see the epoxy and glass combination as the best compromise on performance, cost and weight as it avoids the high costs associated with carbon fibre • Infusion is the most common moulding technique
Carbon and glass fibre	Carbon fibre is usually not used with polyester resin due to its lower strength and because it is difficult to wet the fibre during infusion	• Used to optimise strength, stiffness and weight • Carbon is most commonly used in prepreg or semipreg fabric form for an internal spar or spar cap which is pre-manufactured and cured before moulding into the blade structure

4.1.1.3 Core materials

The foam core consists of structural cross-linked PVC. It is used in sandwich construction and sometimes as an infusion medium. The use of balsa requires good temperature and humidity control and has some natural variation in properties. All blade manufacturers use structural foam or balsa in their designs, and sometimes both. By volume, balsa makes up approximately 40 per cent of the core material used in blade manufacture, with PVC foam (40 per cent) and styrene acrylonitrile (SAN), polyethylene terephthalate (PET) and polyurethane foams (20 per cent) making up the balance.

Figure 102 Structural foam materials

4.1.1.4 Coatings

Surface coatings are designed to provide environmental and erosion resistance, and must be able to repel dirt and be chemically stable. The choice of surface coating is determined by the resin used in the structure of the blade because of the need for strong chemical adhesion. Polyester, polyurethane and epoxy coatings are commonplace on blades.

4.1.1.5 Adhesive

Structural adhesives join the moulded parts of the blade and are formed by mixing resin constituents with a filler material. Epoxy adhesives are used to join epoxy based parts and polyester adhesives for polyester based parts. Adhesives used in blade construction must have strong fatigue properties, similar to those of the main blade structure.

4.1.1.6 Future developments

R&D of materials for wind turbine blades is focused on better understanding and modelling of the materials and the way in which they are used in blades as well as on developing new materials with a balance of properties even better suited to large wind turbine blades.

Research is addressing the use of different ratios of mixed fibres (usually glass and carbon) in a variety of formats, including uni-directional, woven (2D and 3D), non-crimp and non-woven formats to improve mechanical properties and the speed of manufacture.

The addition of stitching or tufting through the thickness and interfacial veils or layers can help prevent crack propagation and delamination. This is important for an application where the maintenance requirements mean that damage initiation and propagation are not tolerated.

Work is also being carried out on resin additives that can be used in the composite material or even the blade coatings, either to improve the mechanical properties or to introduce additional functionality. One example is the addition of electrically conductive materials to provide lightning protection or self-sensing capability.

A number of suppliers and manufacturers are looking at more sustainable materials for use in wind turbine blades. This includes natural resins and fibres and the use of thermoplastic composites which are potentially more easily recycled.

4.1.2 Design and certification

Blade designers seek to optimise energy capture, cost, weight, turbine loads and reliability. The choice of turbine design concept will often determine characteristics such as the stiffness and blade length for a given turbine size.

4.1.2.1 Structure

In all blade designs, the challenge is to create the lightest structure that will only flex within given limits (to avoid tower strike and meet natural frequency requirements) and can withstand both fatigue and extreme loading.

All blades consist of three main components:

- **Shell**. This provides the aerodynamic shape of the blade.
- **Load bearing beam**. In structural terms, a blade is a hollow, cantilevered, taper beam. Different design concepts use a spar, shear webs, and spar caps or a

monocoque approach to create the loadbearing beam in conjunction with the external aerofoil shape.

- **Root end**. This is part of the blade that attaches the blade to the blade pitch bearing. Some blades use a separately moulded root end section, joined to the shells and the spar later in the manufacturing process. This avoids thick laminate layers in the mould which can cause an exothermic reaction in the infusion process. The root end is then either mechanically fixed or positioned with the rest of the blade materials in the mould.

The two most widely used structural concepts in blade design can be classified by the method used to create the load bearing beam.

A spar-based design is used by Vestas Wind Systems and Gamesa and incorporates a separately manufactured spar made of epoxy, glass and carbon (see Figure 103).

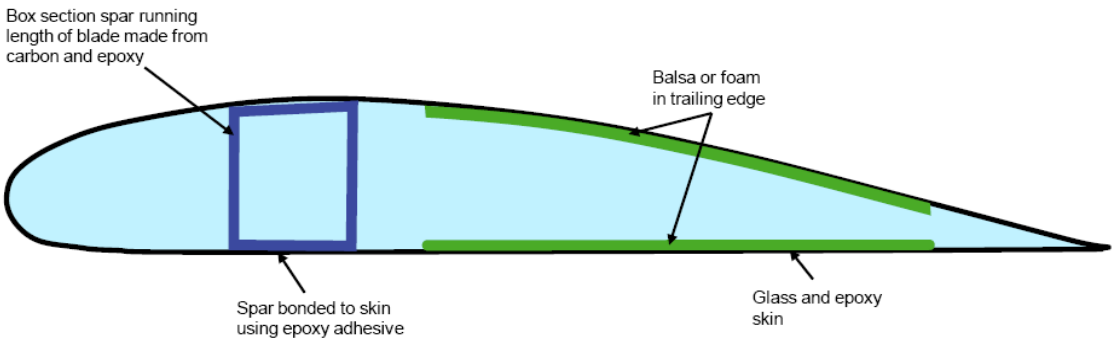


Figure 103 The spar concept

This is assembled and glued into the two shells at the point of mould closure.

The spar cap concept incorporates spar caps (see Figure 104) that generally are made separately and then assembled into each shell. Longitudinal shear webs are used to stiffen the blade and hold spar caps apart. Additional shear webs may be used in the trailing edge section near the widest chord.

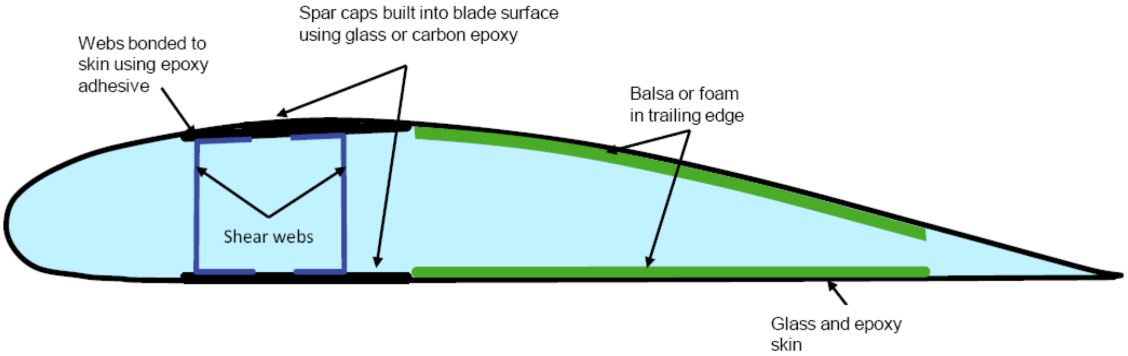


Figure 104 The spar cap concept

4.1.2.2 Design tools and testing

A range of design tools are used in blade development. These can be broadly categorised as:

- Structural design tools, such as finite element analysis (FEA)

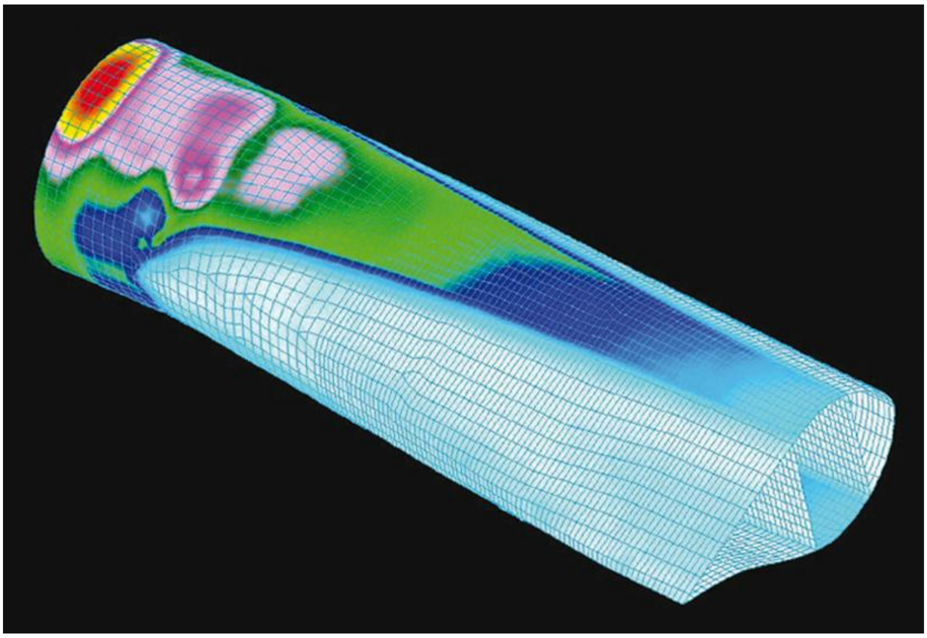


Figure 105 Finite element analysis used in blade design

- Aerodynamic design tools, such as computational fluid dynamics (CFD), and

Quality tools, such as Six Sigma and failure mode effects analysis (FMEA), are procedures to improve the process outputs quality by identifying the potential failure modes and the corrective actions required to prevent failures.

A number of testing processes are used in the blade design process:

- **Material testing**. Extensive load and fatigue testing is carried out on all new materials being considered for use in blades, including materials from a new supplier. This activity is often initially handled by the material supplier with the supervision from the blade manufacturers or in conjunction with them (see Figure 106).

Figure 106 Material fatigue testing

- **Component testing**. Sections or components of blades are load and fatigue tested in order to verify the laminate arrangements and design details (see Figure 107).

Figure 107 Wind tunnel testing on a wind turbine blade section

- **Blade load testing**. Before prototypes are certified and released to the field, new blade designs are tested for fatigue and load on specially constructed test rigs. Three types of tests are undertaken:
    - ✓ Static mode, to verify the survival of the extreme load case, flatwise and edgewise, and
    - ✓ Fatigue mode, both edgewise and flatwise, cycling to simulate full life fatigue loading.

  Tests are normally witnessed or certificated by an external design authority, such as Germanischer Lloyd or Det Norske Veritas (DNV), as part of a design evaluation, which is the precursor to eventual type approval.

Figure 108 The blade testing facility

- **Lightning testing**. Lightning protection systems within turbine blades are tested at specialised high voltage and high current test facilities, such as those operated by Cobham and Narec in the UK and Testinglab Denmark (see Figure 109).

Figure 109 Lightning testing on a wind turbine blade

- **Prototype testing**. The full turbine prototypes are installed and operated before commercialisation. Certification may be granted on a phased basis for prototype and limited production before full serial production manufacture begins, enabling modifications to the design to be made.

4.1.2.3 Future developments

Because deep offshore designs are at an early stage of development, modelling remains one of the main challenges. Experimental floating structures and complete prototypes will be needed to validate the new numerical software tools used to simulate the behavior of floating concepts. Modelling tools combining the turbine and substructure operating conditions are not currently validated for deep offshore designs. In order to ensure successful modelling, the software should be able to analyse the interaction between the aerodynamic and structural behaviour of the foundation (including the moorings) and the turbine simultaneously.

Ensuring that the model is sufficiently developed is an additional challenge. Modelling tools and numerical codes that simulate whole structure behaviour should be developed and validated to allow for an improved design. This will be a first step towards deep offshore development.

4.1.2.4 Certification

Wind turbine designs are certified against IEC 61400 series or Germanischer Lloyd standards by independent bodies. Full type approval will include the following verification and testing processes:

- Design review against design allowable stresses and safety factors
- Material sample testing in both static and fatigue modes
- Static testing of completed blades, and
- Fatigue testing to simulate full life cycles.

It is also normal for a sample blade to be static tested to failure to understand the failure modes. Any changes to the design or materials must be notified to the certifying authority.

4.1.3 Manufacturing

Capital costs. A typical offshore wind blade factory is likely to produce approximately 500 blades a year and will cover up to 30000 m^2. Factory set-up costs, particularly for tooling and infrastructure development depend on the technology selected, as mould tool life, process controls and space requirements are all affected.

Manufacturing cost. Manufacturers constantly work to drive down material, labour and overhead costs. Lean manufacturing concepts and Six Sigma tools are applied to drive year on year improvements and reduce waste.

Speed. The time taken to manufacture blades is a strong focus for innovation in manufacturing processes. The process lead time directly determines the floor area and number of moulds required to manufacture products. The moulding process from an empty mould to removing the blade will be up to 48 hours for large offshore blades.

Quality. Reliability and cost improvement drive increases in the quality of manufacturing processes in all turbine components.

Size. As blades and nacelle covers increase in size, the scale of manufacturing challenges grows.

4.1.3.1 Key processes

The shells and the shear webs or spar are usually made separately and then bonded together. These components are mostly manufactured using prepreg moulding or resin infusion methods, depending on the manufacturer.

Prepreg moulding

Prepreg moulding involves the laying up of structural (glass and carbon fibre) materials that are preimpregnated with resin. These materials are laid in a mould and a vacuum is applied. The mould is then heated to allow the resin to flow between the fibres. The prepreg is then left to cure. Unlike aerospace prepreg processes, autoclaves are not generally used, although heat management in the mould is critical.

The main tooling component of prepreg moulding is the mould. This is by far the most expensive tool used in the process as it must have good temperature control systems. The moulds are more expensive than those used for the resin infusion process. A mould is commonly made of the same material as the blade and is supported in a steel frame.

Resin infusion moulding

During resin infusion, dry materials are laid into the mould. A vacuum bag is sealed in place over the mould and a vacuum is applied. This causes the resin to be drawn from a reservoir in the mould and distributed through the dry materials. The mould is heated to start the curing process. A wide range of manufacturers and market entrants use infusion. The most commonly used system involves infusing two blade halves separately, joining the halves by closing the mould and then gluing the halves together along with internal structural components.

Figure 110 Wind turbine blade mould

Most manufacturers use moulds with integrated heating systems. Moulds are commonly made of glass fibre and epoxy and are supported in a steel frame. Where the blade joining is carried out in moulds, the moulds are hinged either with self-powered hydraulic hinges or mechanical hinges (Figure 110).

Other processes

Other processes carried out during the manufacture of blade include:

- ✓ Painting or gel-coating
- ✓ Non-destructive testing
- ✓ Composite repair, and
- ✓ Blade trailing and leading edge finishing (see Figure 111).

Figure 111 Wind turbine blade finishing

4.1.3.2 Future developments

Blade manufacturers are increasing the level of automation in their manufacturing processes. There is attention being given to automated lay-up processes to improve both the speed and quality of the placement of materials in the mould. This automation is looking at both the placement of preimpregnated fibres in tape form (automated tape laying) and the placement of dry fabrics to produce a preform for subsequent infusion. In this area of development, there are significant synergies between the requirements of the wind and aerospace industries.

Some manufacturers are developing blades shells in multiple parts that are later assembled at the factory or even at the wind farm site. These allow different processes and materials to be used for different sections of the blade and reduce blade transport challenges.

4.2 Nacelle cover and spinner

Offshore nacelles need to be sealed to protect components from the marine environment. As well as providing this environmental protection, the nacelle cover supports anemometry and other auxiliary systems, and acts as a Faraday cage to protect nacelle components from lightning damage. The nacelle mass and volume vary significantly depending on the drive train configuration used by the manufacturer. The typical dimensions of a 5MW turbine nacelle are 10-15mx4mx4m (length x height x width). It does not necessarily follow that turbines approaching 10MW will have proportionately larger nacelles as developing larger turbines is associated with technological and design innovations in drive train configurations. For example, there is a trend towards direct drive (gearless) trains: the new direct drive Siemens 3.0MW nacelle has a mass of 73t, less than the 82t mass of its existing 2.3MW model.

Figure 112 The nacelle cover for the Nordex N90

The spinner or nose cone provides environmental protection to the hub assembly and access into the hub and blades for maintenance personnel. For a large wind turbine, the spinner may be up to 6m in diameter ([32.]).

4.2.1 Materials

The nacelle cover is usually manufactured in a number of sections from glass fibre and may have a mass of up to 20t. It is fitted as part of the nacelle assembly, either before or after the final test, and plays a valuable role in protecting nacelle components during transport to the offshore wind farm site. It is designed to withstand wind loading and allow access to lifting points on the nacelle bedplate for transport and installation.

Typically, the spinner is made from glass fibre in sections and is bolted together with a galvanised steel support. Glass fibre root end collars are normally fitted around blades to provide environmental protection to the blade pitch bearings.

4.2.2 Processes

Resin infusion moulding and resin transfer moulding are commonly used for these components. Both processes use a vacuum to draw resin into the mould. In the case of infusion, the mould is single-sided and a polythene vacuum bag seals the surface. In transfer moulding, a two-part fixed mould is used with a male and female closing to form the finished surfaces. Resin transfer moulding (see Figure 113 and Figure 114) is a lowpressure, closed-moulding process, in which a mixed resin and catalyst are injected into a closed mould containing a fibre pack or preform. After the resin has cured, the mould can be opened and the finished component removed. In exceptional circumstances, wet lay-up is used for prototype or product modifications.

Gelcoat is applied to the mould under extraction to contain fumes and minimise airborne styrene content. Pre-cut fabric and foam are then laid in the mould. After curing, the component is removed from the mould, trimmed and assembled with fittings.

Figure 113 Resin transfer mould tooling for a spinner

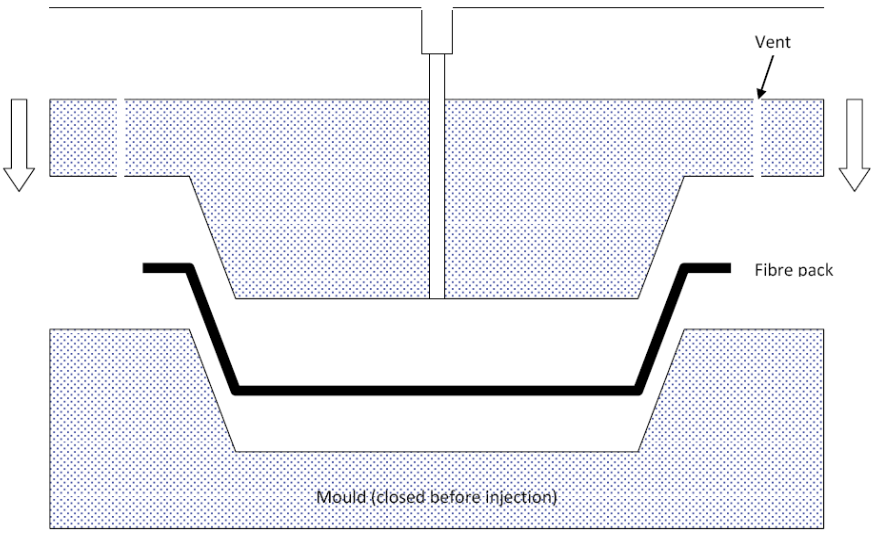


Figure 114 The resin transfer moulding process

4.3 Towers.

4.3.1 Concrete solutions for offshore wind farms

The wind industry's identified need for increased turbine sizes, rotor diameters and tower heights makes concrete a competitive option.

Concrete can deliver economic solutions over the life cycle of a wind farm by providing a wide-range of benefits, such as:

- **Low maintenance** – concrete is an inherently durable material capable of maintaining its desired engineering properties under extreme conditions.
- **Design and construction flexibility** – concrete's versatility enables design solutions, with no restrictions on height or size, to meet any number of site and accessibility constraints.
- **Material flexibility** – concrete mix designs can be finely tuned to optimise key parameters such as strength, stiffness, density and environmental impact.
- **Dynamic performance** – concrete has inherently high dampening properties and can deliver fatigue resistance solution with less noise emissions.
- **Whole life performance** – concrete can deliver durable, large diameter pylons of unlimited height to providing higher levels of power generation.
- **Environmental impact** – concrete construction produces fully recyclable wind towers with significantly reduced levels of embodied energy and CO_2 in comparison to other methods.
- **Upgradeable** – concrete can provide long life wind tower solutions capable of accommodating multiple future-generation wind turbine retrofits.

4.3.1.1 Pylon design flexibility

Precast Design Options

This manufacturing process minimises dimensional tolerances and guarantees a high degree of fitting accuracy during erection. The size and configuration of segments can be altered to take account of lifting capacity available during construction and transportation logistics. In Europe, for example, precast concrete units are being used for 98 to 124m tall pylons ([35.][36.]).

Precast units can be handled individually or as pre-assembled pylon sections comprising numerous precast units joined using prestressing strands.

Concrete units able to flexibly accommodate detailed section changes can be constructed to large diameters without disproportionate increases in cost.

Figure 115 illustrates a typical precast unit configuration to achieve a tapered pylon profile with variable wall thickness. To accommodate project constraints, any pylon cross-section can be made up of either entire precast units, or two or three segmental units joined together. Clearly the latter option may be preferable for sites with access difficulties.

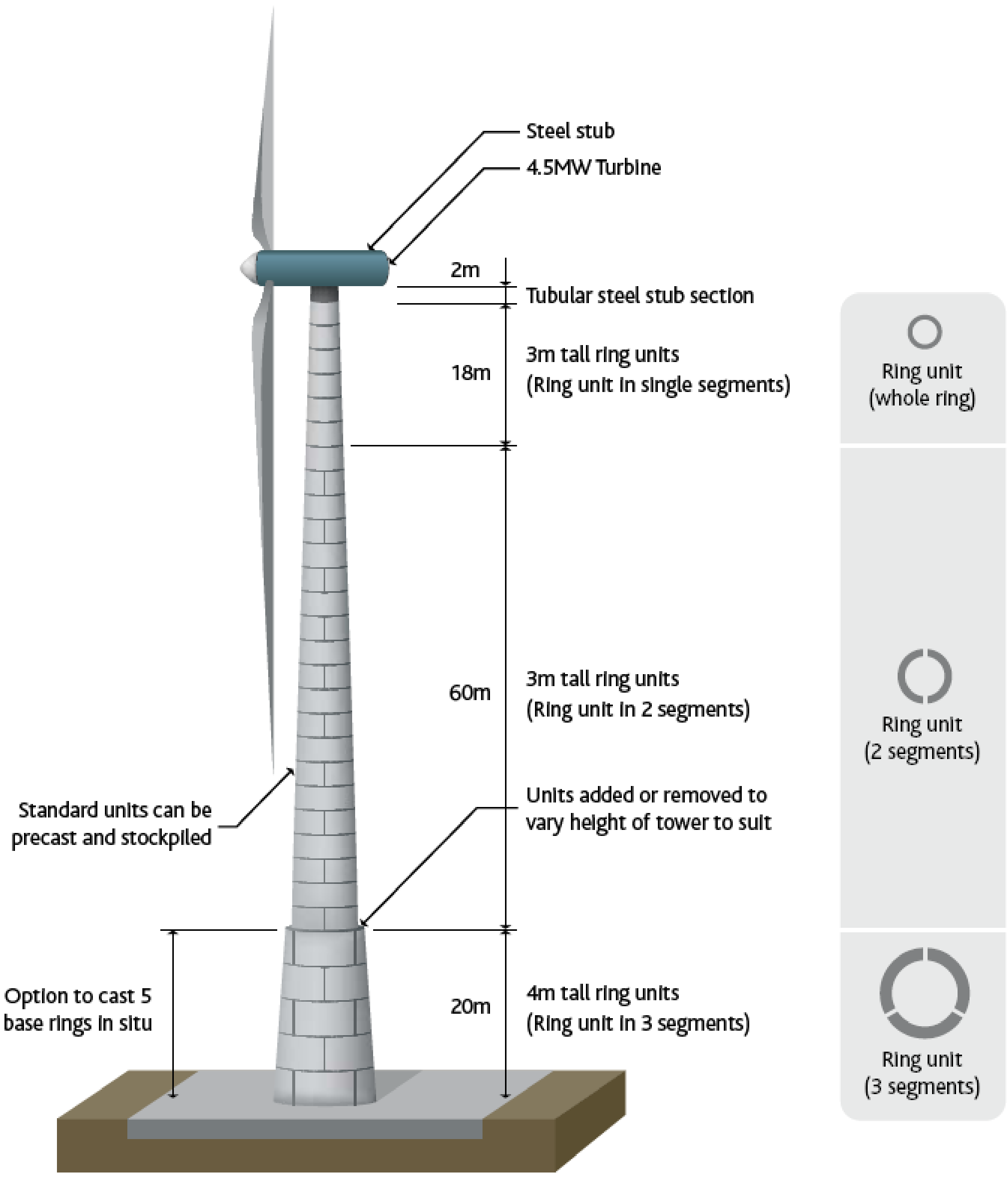


Figure 115 Typical precast concrete configuration

In-situ Design Options

Wind tower pylons can equally be designed using in-situ concreting techniques, such as slipforming, to offer the ultimate balance between maximizing construction capabilities and minimising cost. In-situ construction can overcome limited site access where delivery of large structural elements is difficult.

Slipforming is an entirely crane independent process. Together with accelerated construction times and low labour costs, cost-efficiency is guaranteed for developers.

As with precast, in-situ concrete structures can easily be prestressed to optimise in-service performance.

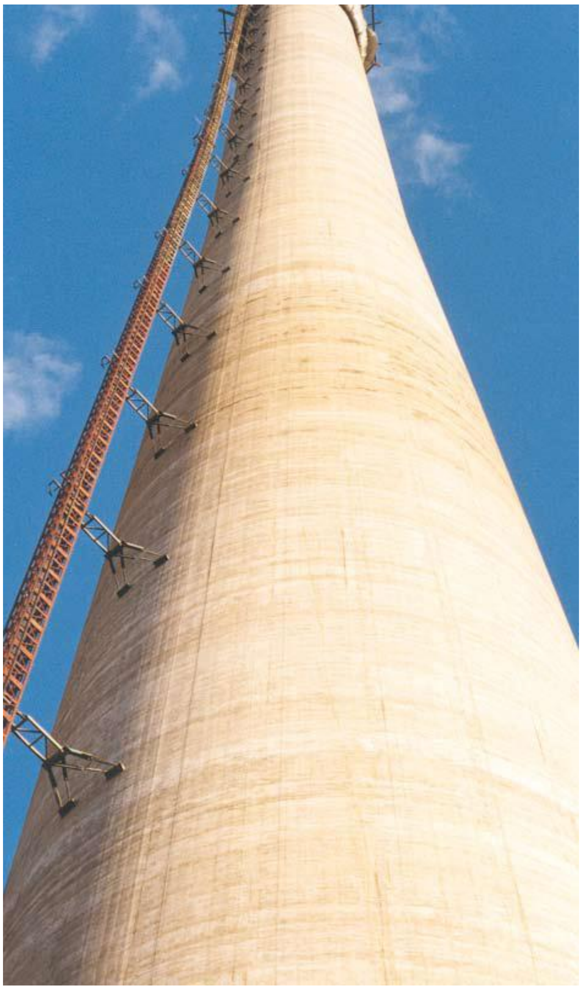


Figure 116 In-situ slipformed concrete tower

Prestressing

The ability to prestress concrete, coupled with concrete's inherent flexibility at the mix design
stage, means that individual wind tower structures can be tailored to provide optimal levels of stiffness and dynamic performance.

The concrete in prestressed structures is placed under controlled compression using tensioned steel or fibre reinforced polymer cables enclosed in ducts to improve stiffness and load carrying capacity (see Figure 117). Ducts can be incorporated into both precast concrete units (under factory conditions) and in-situ concrete (as an integral part of continuous slipforming).

Ducts can be located within pylon walls or alternatively located externally, but inside the pylon structure, to allow thin, light-weight wall construction with simple access for inspection, future capacity upgrades and decommissioning.

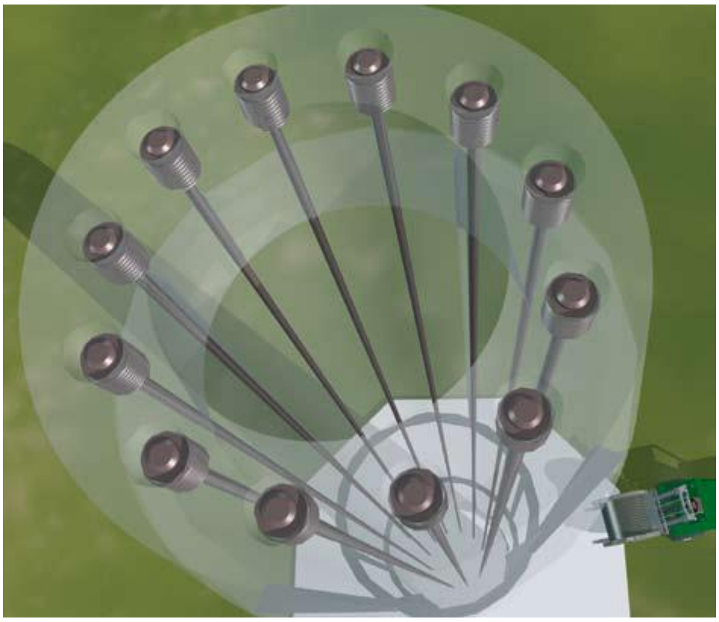


Figure 117 Both precast and in-situ concrete structures can be prestressed to optimize performance

4.3.2 Welding in the fabrication of offshore wind towers

Two welding processes are most commonly used in today's fabrication of tubular wind turbine towers. These are Submerged Arc Welding (SAW) and Flux Cored Arc Welding

(FCAW). More than 90 percent of the total welding for tubular wind turbine towers is performed by submerged arc welding ([38.]).

A tower consists of steel sections, typically two to four, connected flange to flange and bolted together. Each section is fabricated out of several individually-rolled steel cylindrical pieces called shells (cans in the US or cones if cone-shaped), which are first held together by manual tack welding, then welded with submerged arc welding – using a weld robot . Each section is completed by two flanges, which are mounted at the end of the shells by submerged arc welding.

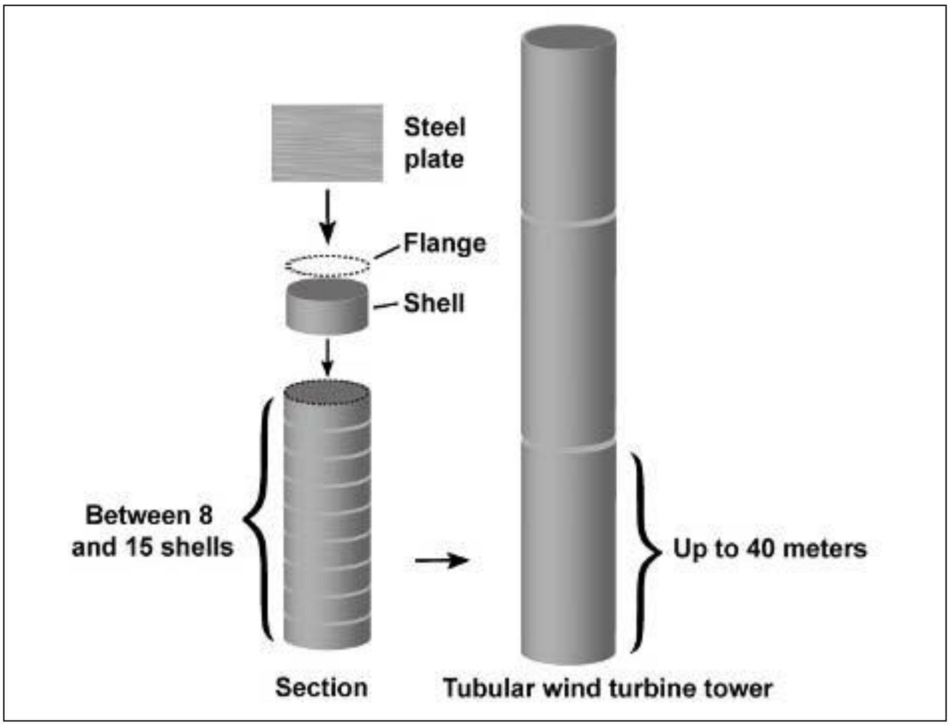


Figure 118 Component layout of the tower

The steel plates used in the fabrication of wind turbine towers vary in thickness from 12 to 75 millimeter depending on the specific design. The larger the diameter, the thinner the material that is required for the tower.

S355 structural steel (European standard) in different qualities is widely used for wind turbine towers because of its high strength and low alloy.

Before welding, the steel plates are prepared for joints in the areas where plates meet. In wind turbine tower production, joint preparation is typically performed by flame cutting due to the substantial plate thickness.

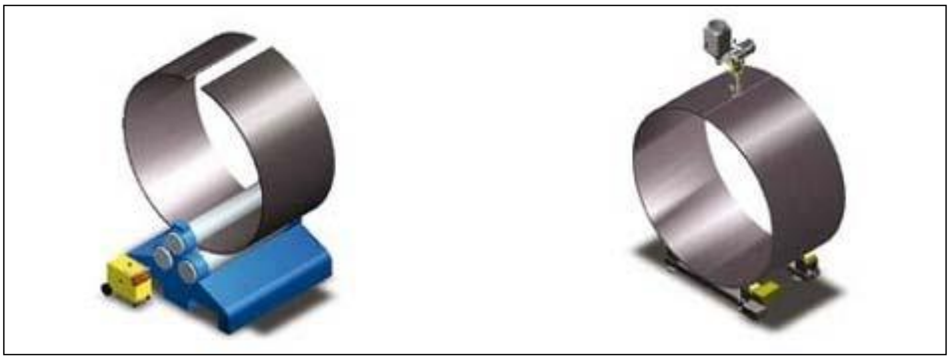


Figure 119 Rolling, forming and tack welding of the shell (on the left) and External and internal longitudinal submerged arc welding (on the right)

The assembling of a section can take place in different ways, using techniques based on roller beds, a head and tail stock positioner or a 'crocodile'.

Head and tail stock positioner

1. One shell (with the flange) is clamped into the withdrawn tail stock, while the second shell is clamped into the head stock in the corresponding manner.
2. The two shells are tightened by pushing the movable tail stock towards the head stock. First tack welding takes place, then external and internal circumferential welding performed by the submerged arc welding process.
3. When the first two shells are joined, a third shell is clamped into the tail stock. Thus, the process continues until the section reaches its full length by approximately 8 to 15 shells. Multi-wired SAW is widely used at this step.

Figure 120 Head and tail stock positioner with roller bed

Assembly using a 'crocodile'

1. One shell (with the flange) is clamped with the 'crocodile'.
2. Using roller beds the next shell is brought into position.
3. First tack welding takes place, then external and internal circumferential welding performed by the submerged arc welding process.
4. The 'crocodile' allows shell-to-flange assembly as well. Multi-wired SAW is widely used at this step.

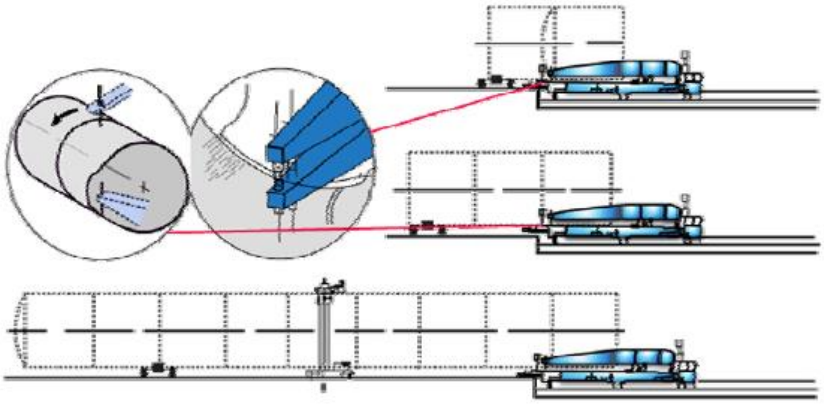


Figure 121 Assembly using a 'crocodile'

Door frames, fittings and platforms are generally welded manually with flux cored arc welding (FCAW), though some manufactures have developed non-welding solutions for these elements.

The tower sections are assembled at the production area, step by step, up to a maximum length of about 40 meters for constraints due to transportation. Finally the sections are transported to the installation site, lifted into place, and assembled using a bolted connection.

4.3.3 Comparison of steel and concrete towers

Table 8 provides an overview and comparison of the features and relative advantages of steel and concrete towers.

Table 8 - Comparison of Offshore Tower Structures' Characteristics

STEEL TOWER	CONCRETE TOWER
Onshore fabrication/construction	
• Fabricate sections in factory under controlled conditions. • Prefabricate in large sections, with welding at shore location. • Larger diameters (5m+) and higher wall thicknesses (60mm+) required for deeper water and larger turbines become relatively more expensive to fabricate.	• Construct at factory facility at suitable coastal site. • Concrete can achieve larger diameters without disproportionate increase in cost. • Concrete can accommodate detailed section changes relatively easily. • Significant initial investment in formwork. • Formwork can be reused over long production runs giving lower unit costs.
Installation	
• Relatively light weight per unit length. • May require fewer lifts (two pylon sections) and shorter weather windows for installation.	• Greater weight per unit length than steel pylon requires more segments and correspondingly more lifts for complete erection.
Performance	
• Taller turbines need larger pylon and foundation diameters, providing sufficient stiffness to control the dynamic response • Larger diameters will require larger wall thickness, making steel harder to procure and fabricate • Larger diameter elements will be more difficult to install.	• A spread foundation (gravity or piled) has potential to give good dynamic response for a large height tower. • Low maintenance. • Prestress can improve durability and provide a good fatigue performance. • Concrete has higher material damping than steel
Maintenance	
• Corrosion protection: high specification paint systems have about 15 to 20 years to first maintenance. • Maintenance is difficult in isolated offshore structures. • Bolted flanges particularly at lower levels are vulnerable to corrosion.	• Highly durable if good quality construction. • Very little maintenance for structure.

4.4 Cables.

Electric energy generated by offshore wind generating facilities requires one or more submarine cables to transmit the power generated to the onshore utility grid that services the end-users of this renewable energy source. Because the power from the wind turbines is generated as an alternating current (AC) and the on-shore transmission grid is AC, the most straightforward technical approach is to use an AC cable system connection to facilitate this interconnection. The most cost effective AC technology for this type of interconnection is solid dielectric (also called extruded dielectric or polymeric insulated) cable, usually with crosslinked polyethylene (XLPE) insulation ([39.]). This is the cable system technology presently used for all offshore wind farms constructed to date primarily as a result of: ease of interconnection, installation, and maintenance; operational reliability; and cost effectiveness.

The following is a brief introduction to cable types and components as it pertains to offshore wind installations.

Insulation

Three types of cable insulation are in common use for submarine transmission for long distances (at least several kilometers.)

Low-pressure oil-filled (LPOF), or fluid-filled (LPFF) cables, insulated with fluid-impregnated paper, have historically been the most commonly used cables in the US for submarine AC transmission. The insulation is impregnated with synthetic oil whose pressure is typically maintained by pumping stations on either end. The pressurized fluid prevents voids from forming in the insulation when the conductor expands and contracts as the loading changes. The auxiliary pressurizing equipment represents a significant portion of the system cost. LPFF cables run the risk of fluid leakage, which represents an environmental hazard. Fluid-filled cables can be made up to about 50 km in length. While LPFF cables are widely installed worldwide, the cost of the auxiliary equipment, the environmental risks and the development of lower-cost alternatives with lower losses, have all contributed to the reduced use of LPFF cables in recent years.

Similar in construction are the solid, mass-impregnated paper-insulated cables, which are traditionally used for HVDC transmission. The lapped paper insulation is impregnated with a high-viscosity fluid and these cables do not have the LPOF cable's risk of leakage.

Extruded insulation is replacing lapped installation as the favored options in many applications. Cross-linked polyethylene (XLPE, also called PEX) is lower cost than LPOF of a similar rating and has lower capacitance, leading to lower losses for AC applications. XLPE can be manufactured in longer lengths than LPFF ([40.]). Until recently XLPE was not an option for DC transmission, since it broke down quickly in the presence of a DC current, but recent improvements allow its use for DC as well. Figure 122 shows an example of an XLPE cable.

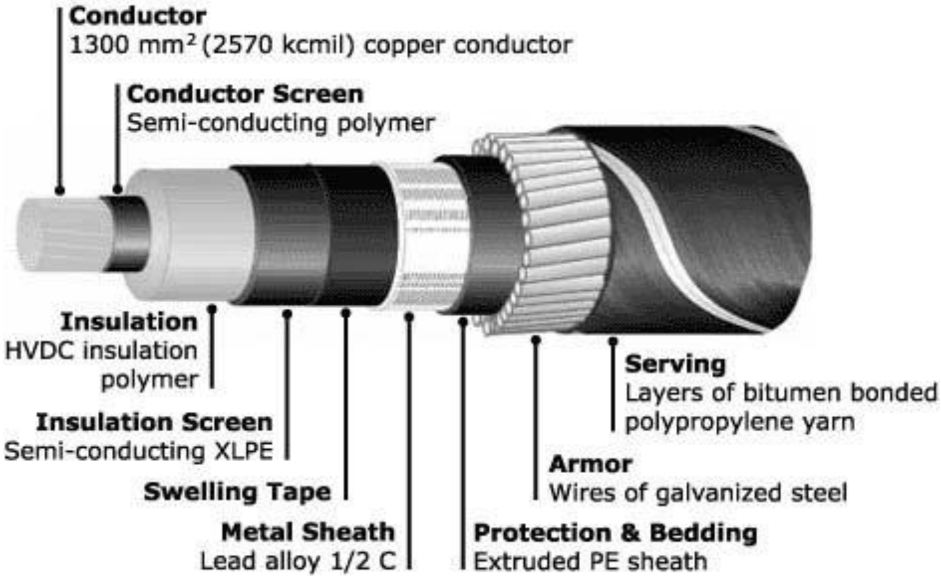


Figure 122 Anatomy of a single-core XLPE cable

Another extruded insulation used in submarine cables is ethylene propylene rubber (EPR), which has similar properties to XLPE at lower voltages, but at 69 kV and above, has higher capacitance ([40.]).

Conductors

The conductor in medium- and high-voltage cables is copper, or less commonly aluminum, which has a lower current-carrying capacity (ampacity) and so requires a greater diameter. Ampacity increases proportionally with the cross-sectional area, which can range up to about 2000 mm^2 before the cable becomes unwieldy and the bending radius is too great. Large cables may have a bending radius as large as 6 m. The design amperage is a function not only of the voltage and the power to be carried, but also the cable length, insulation type, laying formation, burial depth, soil type, and electrical losses.

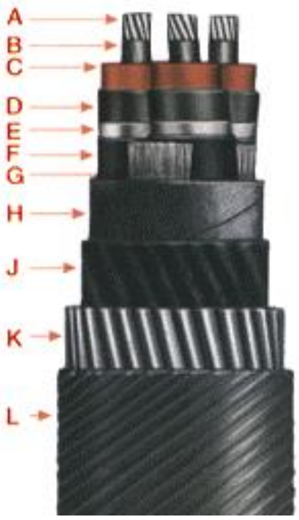
Number of Conductors

When possible in AC-cable applications, all three phases are bundled into one “three-core” cable. A three-core cable reduces cable and laying costs. It also produces weaker electromagnetic fields outside the cable and has lower induced current losses than three single core cables laid separately. As the load requirements and conductor diameter rise, however, a three-core cable becomes unwieldy and no longer feasible. One advantage of single-core cables is that it is easier and cheaper to run a spare. Another advantage is that longer lengths can be made without splices or joints. Figure 123 and Figure 124 show a three-core cable.

Screening

A semiconductive screening layer, of paper or extruded polymer, is placed around the conductor to smooth the electric field and avoid concentrations of electrical stress, and also to assure a complete bond of the insulation to the conductor. Figure 122 shows screening on a single-core cable, and Figure 124 shows a three-core cable with screening on both the individual conductors and the three-core bundle.

Figure 123 Three-core cable (Nexans)



A: Conductor-Copper
B: Strand Screen-Extruded Semi-conducting EPR
C: Insulation-Okoguard
D: Insulation Screen-Extruded Semiconducting EPR
E: Shield-Copper Tape
F: Fillers-Polypropylene
G: Binder Tape
H: Jacket-Okolene
J: Bedding-Polypropylene
K: Armor-Galvanized Steel Wires
L: Covering-Nylon Serving Slushed with Tar

Figure 124 Three-core cable (Okonite)

Sheathing

Outside the screening of all the conductors is a metallic sheathing, which plays several roles. It helps to ground the cable as a whole and carries fault current if the cable is damaged. It also creates a moisture barrier. In AC cables, current will be induced in this sheath, leading to circulating sheath losses; various sheath-grounding schemes have been developed to reduce circulating currents that arise in the sheath. Unlike other cable types, EPR insulation does not require a metal sheath.

Armor

An overall jacket and then an armor complete the construction. Corrosion protection will be applied to the armor; this may include a biocide to inhibit destruction by marine creatures.
Fiber optic cables for communications and control can be bundled into the cables. Note the bundled fiber optic line in Figure 123.
Table 1 summarizes the current availability and limitations of AC & DC cables.

Table 9 - Capacities of high voltage cable

System	AC 3 single-core cables		DC bipolar operation, 2 cables		
Cable insulation type	XLPE polymer	LPOF: Oil- filled paper	LPOF: Oil- filled paper	Mass imp. Paper	XLPE polymer
Maximum Voltage	400 kV	500 kV	600 kV	500 kV	150 kV
Maximum Power	1200 MVA*	1500 MVA*	2400 MW	2000 MW	500 MW
Max. length, km (mi.)	100 (62)	60 (37)	80 (50)	Unlimited	Unlimited

* Losses may be excessive at these powers

The wind industry's move to deeper waters is challenging because transport vessels can only hold so much cable.

5 State of the art from a technological, infrastructural and industrial point of views

The offshore wind energy offers the advantage, in comparison to that onshore, of more favorable conditions of wind with a smaller turbulence to the production of electric energy, of an easier availability of sites and a smaller environmental impact. On the contrary, regarding the maintenance and operability point of view the sea environment and the distance from land involve problems of accessibility to the installations, exposure to the corrosive attack of the salty atmosphere. Then, the phase of realization involves more complex procedures for the transportation and installation of the structures in comparison to the activities on land including the connection to the electric grid.

5.1 Meteorological, geological and marine data measurement techniques.

In order to proceed to the detailed engineering, design and planning it is necessary to acquire some fundamental elements, starting with the meteo-marine data: wind speed and direction and relevant quota of survey, the height and period of the waves, currents, tides, etc). It is also important to know the configuration of the ground on which the installation will take place along with the depth and the stratigraphical composition of the terrain. Finally the sismic characteristic of the area, the intensity of the traffic of crafts etc.

These information will be part of the basis for the design and reference to define the procedures and the means of transportation and installation as well as the adoption of possible protection of the structure against any scouring phenomenon on the foundation ([41.]).

5.1.1 Wind measurement technology.

(Installation of wind measure tower, ultrasonic radar wind measurement instrument, etc.)

The force of the wind is converted into a turning force by acting on the rotor blades of the wind turbine. The amount of energy the wind transfers to the rotor is function of three factors: the density of the air, the rotor area, and the wind speed.

The kinetic energy of a moving body is proportional to its weight and in case of the wind to the density of the air (its mass per unit of volume). At normal atmospheric pressure and at 15°C air weighs 1.225 kg/cm.

The rotor of the wind turbine, in order to capture the kinetic energy of the wind, must slow it down. The rotor area determines how much energy a wind turbine is able to harvest from the wind. Since the area increases with the square of the diameter, a rotor twice as large will receive four times as much energy.

As the wind approaches the rotor, the air pressure increases gradually, since the rotor acts as a barrier to the wind and it will drop immediately behind the rotor. The slow wind behind the rotor mixing with the faster moving wind from the surrounding area will cause turbulence. This effect will be taken into consideration for siting the turbines in the park.

The wind speed is extremely important for the amount of energy that a wind turbine can convert to electricity because the energy content of the wind varies with the cube of the wind speed ([42.]).

5.1.1.1 Anemometers

Meteorologists already collect wind data for weather forecasts and aviation. This information is often used for a preliminary assessment of the general wind conditions in an area but they are not reliable enough for wind energy planning. In most cases the use of these data underestimate the true wind energy potential of the chosen area. Wind speeds are heavily influenced by the surface roughness of the area, by nearby obstacles (such as trees, lighthouses or other buildings), and by the contours of the terrain.

Unless you make calculations which compensate the local conditions under which the meteorology measurements were made, it is difficult to estimate wind conditions at the site. In consideration of the heavy investments associated to the wind industry, it is therefore important to make accurate measurements.

The device for measuring wind speed is called anemometer. The term is derived from the Greek word anemos, meaning wind, and is used to describe any airspeed measurement instrument used in meteorology or aerodynamics. There are available different types of anemometers.

Cup anemometer is a simple type of anemometer. It has a vertical axis and three or four hemispherical cups mounted on one end of three or four horizontal arms fitted on the vertical shaft. The hollow of one cup is always presented to the wind blowing wich makes the vertical shaft turning in a manner proportional to the wind speed. The number of revolutions per minute is registered electronically. Normally, the anemometer is fitted with a wind vane to detect the wind direction.

For wind resource assessment studies the industry currently uses the three cup anemometer that presents a more constant torque and responds more quickly to short blasts of wind than the four cup anemometer.

Figure 125 Campbell Scientific - three cup anemometer and wind vane to measure wind speed and direction

Hot wire anemometers are based on the electrical resistance of a very fine wire (tungsten of some micron diameter) electrically heated. Air flowing past the wire has a cooling effect on the wire. As the electrical resistance is dependent upon the temperature of the metal, a relationship can be obtained between the resistance of the wire and the air flow speed.

Though extremely delicate, they have high frequency-response and fine spatial resolution compared to other measurement methods, and as such are universally employed for the studies of turbulent flows.

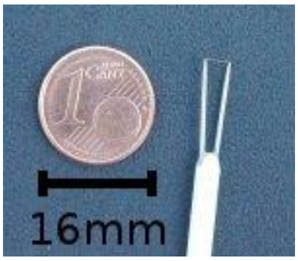


Figure 126 Hot-wire sensor made of tungsten electrical resistance

Laser Doppler anemometers use a beam of light generated by a laser. Particles in the air reflect the light back into a detector, where it is measured relatively to the original laser beam. The motion of the particles produces a Doppler shift for measuring wind speed in the laser light.

Figure 127 Natural Power's ZephIR 300 installed on RWE Dea UK's gas platform at 125km from shore. The laser beam is focused at each user-configured height from 10m to 200m above platform level

Sonic anemometers use ultrasonic sound waves to measure wind velocity with very fine temporal resolution, which makes them well suited for turbolence measurements. The lack of moving parts makes them appropriate for long term use in exposed automated weather stations where the reliability of traditional cup anemometers is affected by salty air or large amounts of dust. Disadvantage are the distortion of the flow itself by the structure supporting of the transducers, which requires a correction and the lower accuracy in case of precipitation that causes a variation of the speed of sound.

Figure 128 Ultrasonic Anemometer - YOUNG Model 81000 with 3 opposing pairs of ultrasonic transducers for high resolution and three-dimensional wind measurement.

Cup anemometers tend to be more utilized even though they are more sensitive to extreme weather conditions. A part from the type of anemometer being utilized, what is more important in the wind energy industry is the quality of the instrument utilized.

Cheap anemometers are not recommendable for wind speed measurement in the wind energy industry, since their low accuracy and poor calibration may entail measurement errors in the range of 5 to 10%.

This range of error may produce a value of energy content much higher than in reality since the energy content varies with the cube of the speed and the subsequent economic decision may be heavily affected.

Having acquired a good quality, well calibrated anemometer, the next step is to identify the most suitable location for its installation in order to have an accurate measurements of the wind speed. The anemometer should be installed on the top of a mast having the same height of the hub of the wind turbine to be used. The mast preferably should be made by a thin cylindrical pole in order to minimise the disturbances of airflows from the mast itself and. If it is to be placed on the side of the mast it is essential to place them in the prevailing wind direction in order to reduce the error.

The data on both wind speeds and wind directions from the anemometers are registered on a data logger, and regularly transmitted or collected.

5.1.1.2 The Wind Rose

The information collected relevant to the distributions of wind speeds, and their directions are drawn on the so-called wind rose. In the standard set by the European Wind Atlas the wind rose is divided in 12 sectors (one for each 30 degrees of the horizon). Alternatively it may be used a different representation in 8 or 16 sectors.

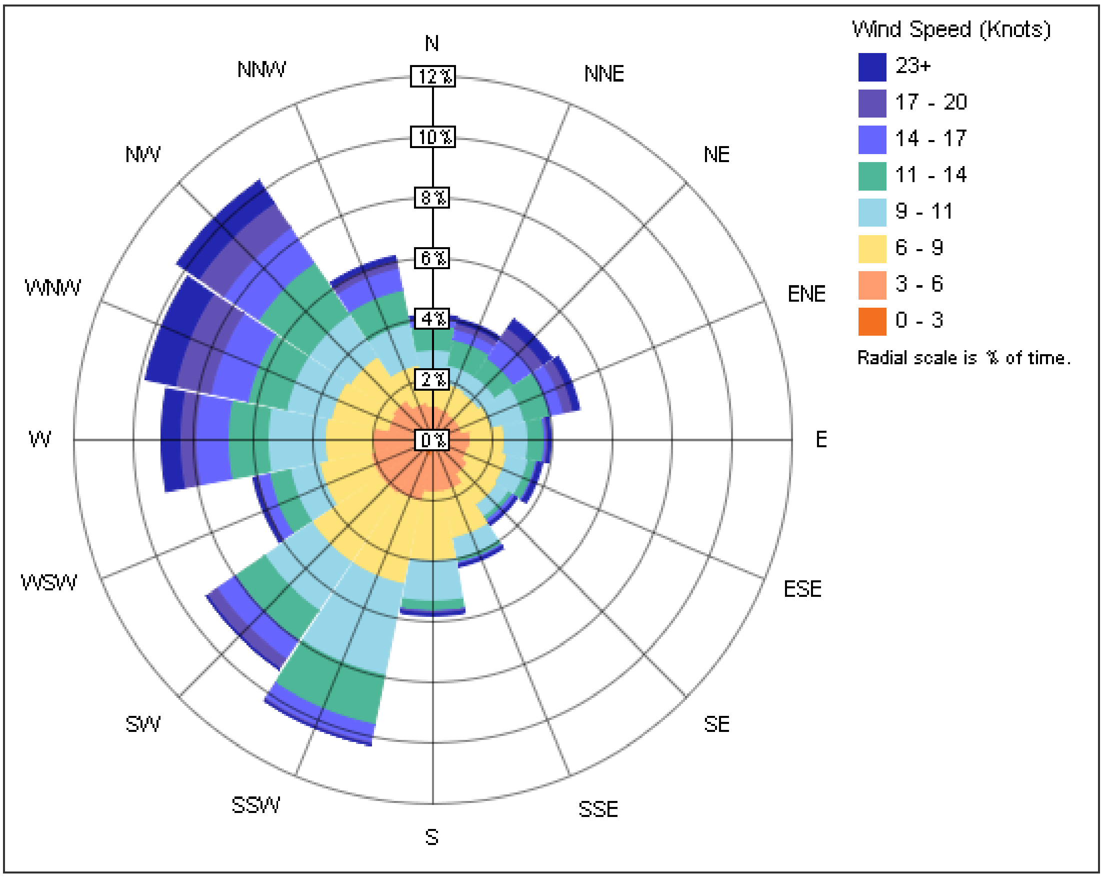


Figure 129 Wind rose: speed distribution

The relative frequency (the outermost radius) represents how many per cent of the time the wind is blowing from that direction. Each radius is divided in intervals of wind speed, represented by different colours. Each interval tells us how much it contributes to the average wind speed at that particular location.

Other type of wind rose shows different information as: frequency, mean wind speed, and mean cube of wind speed. This latter indication gives for each sector the energy content of the wind that is the most interesting data because it shows where to find the best power to drive the wind turbines ([42.]).

If we have measured the wind speed exactly at hub height over a long period at the exact spot where a wind turbine will be installed we can make exact predictions of energy production. However the industry usually rely on one year of local measurements, and then use long-term meteorological observations from nearby weather stations to adjust their measurements to obtain a reliable long term average. In practice this can be done with good accuracy, except in cases with very complex terrain.

The use of the wind rose is extremely convenient for siting wind turbines since it indicates where the largest share of the energy in the wind comes from.

National and international Authorities have developed wind maps to assist the Countries and Regions in defining the most suitable areas to be allocated for wind parks. The maps can be profitably utilized by wind project investors to identify the possible best wind fields.

The maps, however, are not sufficient for actually locating a wind turbine. In order to make proper calculation of annual electricity output one would have to go to the prospective location and carry out a detailed verification in the terrain in order to ascertain the roughness, locate obstacles and check for buildings, trees etc.

5.1.2 Geological and marine data measurement techniques.

Besides the definition of the wind conditions representative of the specific site at which the offshore wind turbine will be installed, the design of the support structure of the offshore wind turbine requires also a carefull assessment of the external conditions at the intended site in order to guarantee its structural integrity. This assessment therefore represent a very important preliminary activity and will consist of a site survey of the seabed soil conditions along with assessement of the marine conditions including the occurrence of extreme conditions of waves, currents and tides in a period of 50 years. The presence of sea ice, marine growth and any possible scouring phenomenon and seabed movement growth may influence hydrodynamic loads, dynamic response, accessibility of the structure and therefore a preliminary assessement and evaluation must be considered.

5.1.2.1 The geophysical, geotechnical survey of the location

Objective of the survey is the data gathering necessary for the engineering and installation of the foundation and of the cable connecting the wind turbine to the shore. Basically it will ascertain:

- the seabed morphology, nature, characteristics and conditions
- the sub seabed stratigraphy
- the presence and position of the existing facilities or wreckages nearby
- any other helpful information related to activities in the area such as fishing, ship traffic or other human involvements and any evidence found during the survey.

The first phase of on-site investigation, commonly referred to the geophysical survey, employs remote sensing technology, often multi-beam sonar (Figure 130) and/or high-resolution seismic reflection (Figure 131). This phase, known as hydrographic surveying, generally provides a detailed bathymetric map of the sea bottom as well as general soil characteristics. Both techniques rely on a vessel-mounted array of energy emitters and receivers that can carry out the initial site investigation in a relatively short period of time. Advanced design work usually requires direct sampling of bottom soils, typically at each foundation location. This phase of investigation involves vibracore sampling (Figure 132) to depths of up to 10m or conventional borings to much greater depths. Retrieved soils are analyzed to determine their textural and engineering properties.

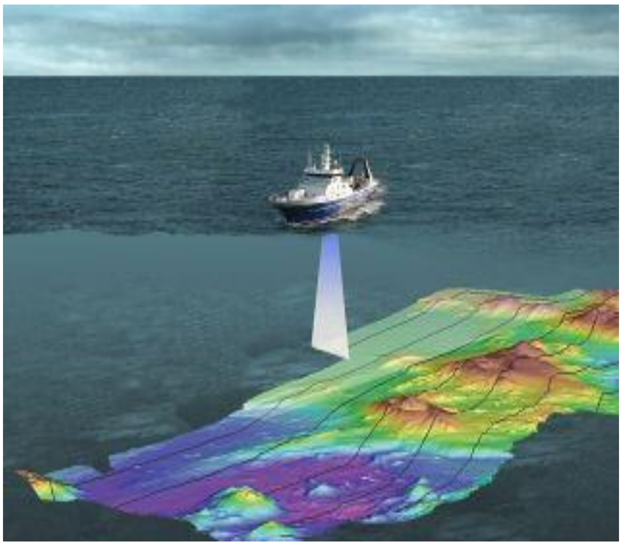


Figure 130 Seabed bathymetric analysis

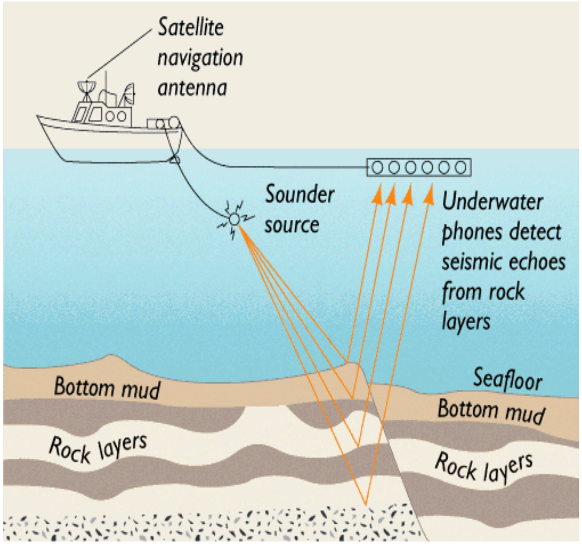


Figure 131 Seabed analysis by reflection method

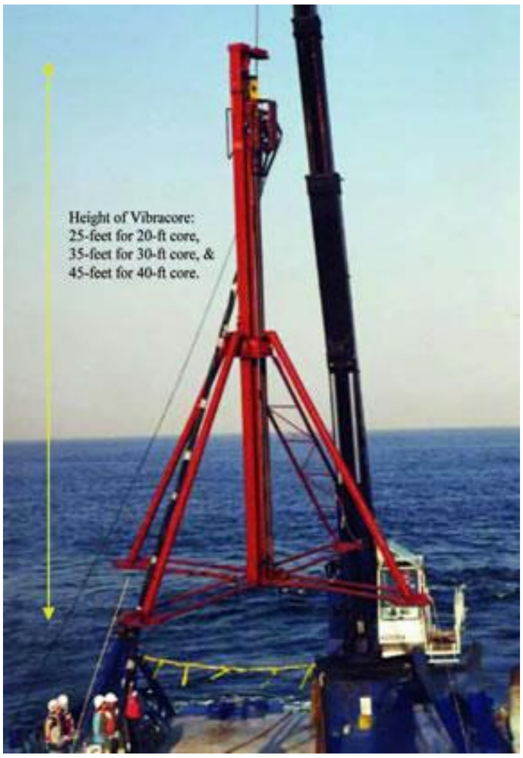


Figure 132 Seabed sampling by vibracore technology

A geophysical survey along the cable route is also required. It can be performed utilizing an AUV (Autonomous Underwater Vehicle) equipped with Multi beam Echo-sounder, Side Scan Sonar and Sub-Bottom Profiler systems, on a corridor centred on the cable route.

Full bathymetric and Side Scan Sonar coverage of the seabed and magnetometer survey is required. Particular care shall be paid in identifying any seabed obstructions, irregularities, hollows and in particular the position of any crossing with existing installations.

The geotechnical investigation program includes:

- one continuous PCPT (Piezo Cone Penetrometer Test);
- one Vibrocore sample to 5 m depth from seabed;
- one Box corer sample.

Laboratory analyses for the box corer samples are the following:

- Soil Unit Weight;
- Undrained Shear Strength;
- Remoulded Undrained Shear Strength;
- Atterberg Limit;
- Grain Size;
- Water Content.

5.1.2.2 Water depths, waves, tides and currents

Waves and Currents

Everyone has seen waves on oceans. They are actually energy moving across the ocean's surface. The water particles only turn in a small circle as a wave passes. Wind provides the energy through friction between the air molecules and the water molecules.

Every wave is characterized by a:

- height, the vertical distance from the crest (high point) to the trough (low point).
- Length, the horizontal distance between two adjacent crests
- period, the time it takes for two successive waves to pass a particular point
- frequency the number of waves that pass a particular point in a given time period

- amplitude the distance from the crest or the trough to the ideal level of the ocean without any waves (still-water line).

Wind speed, duration, and fetch (the distance it blows over open water) determine how high a wave grows. The greater these three parameters are, the larger the wave is ([43.]).

Oceans currents, like waves, are always moving about in the sea. But whilst waves are affected by winds, as we have seen, the differences in temperature between the cold waters of the poles and the warm waters near the equator originate currents. Currents are also caused by tides, rain and ocean bottom topography.

Wave, current and water level data are important parameters to be monitored. A broad data base including water depth, 3D currents and wave height, speed and direction is essential to ensure a safe and secure design of the offshore installations.

In the chapter relevant to wind measurement it has been underlined that wind maps developed by National or International Authorities can be profitably utilized to identify possible best wind fields. A preliminary assessment of the marine conditions for an intended site may refer alike to regional elaborations prepared by state/national Agencies.

In the picture is shown the RON - Rete Ondametrica Nazionale (Wave Observational network) of The Hydrology Department of the Agency for the Protection of the Environment and the Technical Services (APAT) in Italy. The punctual observations collected through the observational network are extended to the areas not covered by instruments making use of mathematical models ([44.]).

Figure 133 National wavemeter network

Regional elaborations, however, are not sufficient for the local assessment of the actual marine conditions and it may be necessary to go to the prospective location and carry out a detailed verification of the local marine conditions.

Several instruments and integrated systems have been developed integrating a wide range of sensors onto a buoy to be deployed offshore to record and transmit ocean date in real time.

The data sets commonly used in the industry include meteo parameters, wind speed, direction and gust, wave period and direction, significant and maximum wave height, current speed and direction. The instrumentation can be configured with a variety of telemetry option, powered by solar panels and rechargeable batteries and can be complemented by software for data storage and management.

As an example in the figure below is shown the Triaxis Directional Wave Buoy. The wave parameters and sea surface temperature are collected, processed and logged on the buoy and then transmitted via satellite telemetry to a base station. The buoy can be easily rolled off a ship deck and moored with standard mooring configurations depending on the water depth.

The same buoy can be equipped with a combined wave and current measuring device. This dual function buoy measures directional waves and 3D currents accurately and precisely.

Figure 134 Triaxis Directional Wave Buoy

Tides

In oceanography, tides are commonly defined as the periodic variations in sea level that occur as a result of the gravitational forces of the Sun and the Moon ([43.]).

Tides vary on timescales ranging from hours to years due to numerous influences the Earth's rotation, the revolution of the moon around the Earth and the sun's gravity. The exact time and height of the tide at a particular coastal point is also greatly influenced by the local bathymetry. To make accurate records, tide gauges at fixed stations measure the water level over time. Gauges ignore variations caused by waves with periods shorter than minutes. These data are compared to the reference (or datum) level usually called mean sea level.

5.2 Installation and maintenance.

In siting the winds turbine it must be taken into account the orography of the area and the presence of obstacles which may create turbulence decreasing the possibility of using the energy in the wind and imposing more tear and wear on the turbine. Therefore towers for wind turbines are usually made tall enough and the spacing of wind turbines is between 5 and 9 rotor diameters apart in the prevailing wind direction, and between 3 and 5 diameters apart in the direction perpendicular to the prevailing winds.

The wind at sea is generally less turbulent than on land due to the fact that temperature variations between different altitudes in the atmosphere above the sea are smaller than above land. Therefore turbines located at sea may be expected to have a longer lifetime than land based turbines.

On the other end, transportation and installation of the structures and subsequently the operations and maintenances ask means fit for transportation and lifting, suitable procedures taking in account the static and dynamic loads that act on the structures, the conditions of the seabed and its stratigraphic composition, the water depth and the hydrodynamic and aerodynamic regimes of the sea (winds, waves, currents and tides) that can heavily affect all the operations.

The major challenge for offshore wind energy is cutting costs ([45.]). Undersea cabling and foundations represent a very expensive part of the project. Progress have been made to reduce construction costs of the offshore wind turbines to take advantage of the fact that the offshore wind conditions are generally much more favourable than the onshore sites and may yield 50% higher energy. Today, at least for shallow water depths, the economics of the offshore wind industry appear quite competitive to onshore one. All that thanks to an advanced design and technology for towers and foundations that has contributed to ease construction procedures and reduce the weight and consequently transportation costs are lower. It should be noted that towers and foundations represent a fairly heavy part of the wind turbine and an important item of the budget.

5.2.1 Port Availability.

The infrastructure for the developments of offshore wind farms should offer the maximum flexibility in order to reduce the logistical costs. Space requirements differ substantially depending on the phase considered (construction, installation, operations and maintenance) and for each phase depending on the type of technology involved (i.e. turbines on fixed foundations or on floating systems, devices to be installed etc.).

For construction purposes there may be need of several hectares of ground suitable for lay down and pre-assembly of products taking into consideration that the need of available space for offshore wind equipment with fixed foundations will differ substantially from the floating systems. Floating structures for wind energy are generally very large structures, sometimes directly assembled into water before being towed offshore.

In any case it is advisable that the manufacturing facilities be located close to the port facilities with a railway/road direct access.

Ports for wind farm installation must be able to accommodate vessels of up to 140 m length, 45 m beam, and 6 m draft (for turbines on fix foundations), with no tidal or other access restrictions. The overhead clearance to sea should be of 100 m minimum, to allow vertical shipment of large components such as towers.

Ports must have an adequate laydown area supporting large offloading equipment for turbine components. Typically, the available port laydown space should be roughly three-quarters to one acre of land area per turbine (see Figure 135). Ideally, if additional adequate space is available at the installation port, hub and blade assemblies can be constructed onshore. Placing manufacturing and assembly facilities at a single site becomes increasingly advantageous in terms of costs and logistics, minimizing the number of offshore crane operations per turbine installed and making the construction schedule less sensitive to weather delays.

In the North Sea, particularly in Denmark and Germany where there is a high concentration of industry players, many ports have already been used for offshore wind activities and several of them are already well established as manufacturing and construction facilities.

On the contrary in the Mediterranean area no offshore renewable energy installations are currently present and therefore deeper studies for the future development of infrastructure in this area are required. Due to the large number of countries bordering the Mediterranean basin, coordinated action on infrastructure and coordination of the initiatives are important.

It should be noted that, as technologies evolve towards deeper water, floating devices etc., the construction, port, and installation requirements will also change.

A port nearby to the wind farm is also essential to accommodate the O&M activity during the operational phase. However, the requirements for port specifications are far less demanding because of the much smaller size of service vessels and the limited requirements for any laydown area. A landing location for a service helicopter may be desirable if this mode of transport is used as an alternative to surface vessels, especially when sea conditions frequently limit the use of surface vessels (see Figure 136) ([46.]).

Figure 135 Port of Mostyn Construction Base for Burbo Bank Offshore Wind Farm (UK)

Figure 136 Helicopter Access to Vestas Turbine

The port characteristics are described hereafter.

Port Identification

- Port Name
- Country
- Port Owner
- Contact Address: Telephone Fax Email Website Coordinates

Access Details

- Port Depth, Entrance Width and Tidal Range
- Maximum Vessel Size (LOA, Draught, Beam)
- Tug Assistance Availability and Piloting Information
- Turning Area Availability
- Rail Links, Major Roads, Private Internal Road Links, Distance to Helipad and to International Airport
- Number Of Cranes, Quay Length and Loading Capacity
- Storage Space Development Land Availability
- Any Other useful information and Comment

Supply Chain Capabilities and Services for

- Installations Base
- Operations and Maintenance Base
- Supporting manufacturing of Towers, Blades, Foundations, Cables
- Provisions and Supplies of Water, Fuel Oil, Diesel Oil,
- Maritime services
- Dry Dock
- Warehousing
- Security

5.2.2 The carriage.

The operators of offshore wind parks using for the marine activities, vessels and operational procedures mainly borrowed from the offshore oil industry. Basically the service vessels requested in routine operations are:

- Personnel Transfer Vessels
- Multi-purpose Vessels (see Figure 137)
- Jack ups
- O&M Vessels
- Dive Support vessels (see Figure 138)
- Survey & ROV support vessels

Generally speaking, the boats are expected to work in challenging environments. Therefore the vessels for the transfer of personnel and equipment between the shore and wind turbines must be robust, fast and seaworthy, some should be ice classed, with comfort and safety of passengers.

Multi-purpose vessels, in addition to providing personnel transport, act also in support to wind farm construction and as general support vessels during maintenance periods.

Figure 137 Seminole Micoperi – Multipurpose vessel

Jack ups (propelled or non-propelled) are barges that raise themselves above the water on legs by means of an hydraulic jacking system. They are used for piling, for assistance in erection of turbines, to store materials and equipment, etc.

Typical work undertaken would be:

- Anchor handling
- Towage and handling of transport barges, rock barges
- Transfer of personnel, cargo and equipment, with vessels' own crane
- Plough dredging & bed levelling
- Use as a dive platform and operate ROV
- Hydrographic survey
- Subsea equipment deployment

In addition they provide support to:

- Offshore wind farm construction
- Cable laying operations
- Dredging support
- Salvage operations

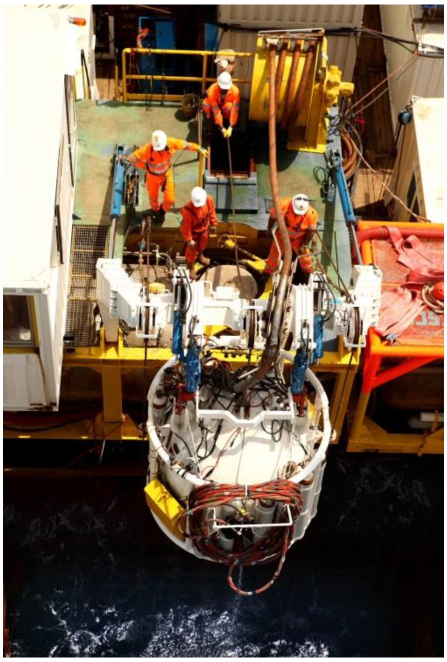


Figure 138 Dive support vessel handling saturation equipment

The continuous growing activity in the development of deep offshore wind parks has prompted marine contractors to expand a fleet built on purpose for offshore wind farm to cover the activities during construction periods, commissioning and O&M, capable of safe and secure docking with offshore wind turbine. In particular they have also investigated the feasibility of vessels specifically designed for transportation and installation of offshore wind farms. All the vessels are to be built to class to conform European rules, and designed to work in hostile coastal environments.

5.2.3 Offshore Wind Farm Installation Vessels

Two specific aspects appear to be the most critical with the new generation of the deep water offshore wind turbines. One is the stability during the crane utilization; the other is the ability to cope with the new generation of offshore foundations. For the economy of the project, it is important to provide a cost efficient means that is unrestricted by factors such as water depth, type of sea bed, and capable of transporting pre-assembled foundations cutting down the time and cost of installation.

The ideal installation vessel should be a mix design between a jack up and a crane vessel which, as the need arise, will pull the complete hull out of the water. Nowadays this type of vessels may be considered almost a standard for the vessels dedicated to the offshore wind farm installation even with different capabilities and range of application.

When the ship is in transit the legs are protruding some tens meters high into the air. Once arrived on location they are pushed down to the sea bottom where penetrate, depending on the soil conditions, up to some few meters. The ship is lifted above the waves providing a stable and solid platform for the lifting operations. The windmill is fixed into place using a crane from the ship. These giant jack-up vessels, on purpose-built for this expanding industry, help to overcome the difficulties of working at sea. On average, it takes from 24-36 hours to install wind turbine foundations up to three days if drilling is required.

Specifications to be addressed in the selection of a fit to work vessel are relevant to the offshore cranes with adequate tonnage capacity, a class compliant dynamic positioning control system with thrusters for propulsion and steering, backed up with an independent control system in the event of DP system malfunction, a marine automation system for monitoring and control of the vessel's operational functions (ballast, fuel oil and cooling water, diesel generators, high voltage switchboards and thruster), a class compliant communication and navigation systems for worldwide operation (dual radar systems, HF/MF and VHF systems, Inmarsat-B and Inmarsat-C communication systems, an independent autopilot system, marine echo sounder and water speed doppler log unit), a weather forecast system. The regular crew is complemented with the addition of the erection team during turbine installations.

An example of an Offshore Wind Farm Installation Vessels is shown in Figure 139.

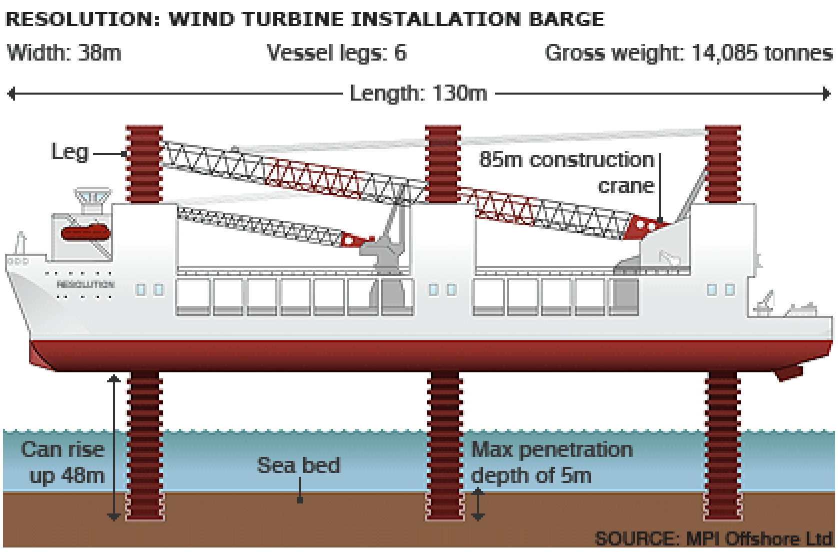


Figure 139 Offshore Wind Farm Installation Vessels

5.2.4 Offshore Wind-Farm Maintenance Vessel

The current wind farms closer to shore are serviced by fast catamaran and monohull boats which go out from the shore in good weather conditions. The sheer distance and exposed location of several wind farms make service from a port difficult, expensive, risky and time wasting.

Recently it has been introduced a concept of new offshore wind farm maintenance vessels. The idea behind is to improve uptime of deepwater wind turbines and reduce maintenance costs and carbon emissions. Most of the actual and future deep water wind farms will be a long way offshore, up to 110 km, with thousands of turbines that require a routine maintenance program to be carried out in addition to any repair or replacement of critical components due to wear and tear.

The Maintenance Vessel, located at the centre of the wind farm, acts as a dedicated mother ship offering a solution to the logistics problem of carrying out simultaneous maintenance of multiple wind turbine. To this end the vessel provides accommodation and recreational facilities for maintenance engineers, service personnel and support crew, extensive storage and workshop areas.

Figure 140 DP vessel with heave compensated gangway in operation

The vessel has a dynamic positioning capability, a dry/wet dock, helicopter support facilities, cranes for loading stores from support vessels. Crew change and supplies will be carried out using a dedicated support vessel with the option to using large helicopters. She can support helicopter operations in addition to the workboat deployment and fitted with a heave compensated access walkway for accessing the wind turbines.

With a capability to service up to several wind turbines per day in significant wave heights (up to 2.5 m), providing a secure offshore maintenance base from which workboats can be deployed, keeping them and their work crews safely on site in deep water wind farms far from shelter. By remaining on site rather than returning to port between maintenance visits it will be reduced transit time and energy getting to and from the fields, and the use of good weather windows will be maximised. That means savings in cost and energy used for maintenance, reduction of non-operational downtime and increased turbine availability ([47.]).

5.2.5 Transport and Installation procedures

Erection of wind farms and systems for handling ever larger components has progressed since the early commercial projects of the 1980s. For a period up to the mid 1990s, the allowable mass of components to be lifted to hub height was determined by available cranes. Subsequently, there has been a shift, indicative of the maturity and growth of the wind industry, where crane manufacturers are producing designs specially suited to wind farm installation.

Often complete rotors are lifted on to nacelles. Sometimes hub and blades are lifted individually.

The Enercon E126 exploits a jointed blade design to facilitate transport, handling and erection of the rotor components. The blade joints are made up in the air. Thus, rotor erection practice moved through size ranges where complete rotors were crane lifted, to size ranges where hub and blades were lifted individually, and now to the E126, where blade parts are lifted individually.

Figure 141 Erection of Nordex Wind Turbines

A wind farm of Nordex N100 wind turbines (the largest Nordex wind generators in the US) was erected (Figure 141) over a five mile long ridge south of Wadena, Minnesota.

This project made first use of the new 2007 DEMAG CC2500-1, a 550 ton crawler, a crane with 126m of main boom with jib combination to 168m. Transport of the CC2250-1 with maximum boom and counterweights requires 36 truckloads. This assembly approach for a wind farm involving whole rotor lifts of 100m diameter rotors contrasts strongly with the erection strategy of the E126.

5.2.6 Occupational Safety

The conditions that the working activity in a marine environment offer is not only rather uncomfortable but also dangerous to the workers' health. There is a constant danger in everything a worker does, with a potential to prove fatal if care is not taken. Ensuring safety is a responsibility of all, owners, managers, supervisors and workers.

No work in the winds industry happens at small scale. The machinery used is huge, often requiring adeguate skill and strength to be handled. A minor discrepancy while working at such machinery can prove to be fatal for any worker. The seriousness of injury can be as bad as death, in some cases.

There are several precautions that need to be taken. With correct measures, a lot of these problems can be tackled even though there is still a long way to go. Few things can help ensuring occupational safety and health.

No one is more responsible for safety than the workers themselves once properly trained on measures to be taken to maintain safety and on how handling the equipment.

Safety depends, up to a large extent, on the entire working environment where safety measures should be ensured in and around the working space (i.e. during servicing it is essential that the machinery be stopped completely by applying the mechanical brake and locking the rotor in place with a pin, to prevent any movement of the mechanical parts).

Protective gears like goggles, gloves, floatation devices when working over water, full body harnesses when working at high levels must always be worn at all times.

Figure 142 Protective gears and fall protection and retrieval

In most cases, this helps in preventing an accident to a great extent or can help in keeping the degree of severity of accident to the minimum levels (i.e. in case of a fall a set of straps connected with a steel wire to an anchoring system equipped with a shock absorber that follows the person while climbing or descending the turbine keeps persons reasonably safe).

In end, nothing promotes occupational safety and health better than communication to extend knowledge about various aspects and to discuss about problems being faced by workers.

It should be noted that the occupational safety is governed by a number of national and international regulations that must be strictly followed.

5.3 Cables Requirements, cables installation and laying operations

5.3.1 Submarine cables requirements.

The minimum requirements of submarine cables shall comply with laws and regulations in force in the Country where the cables will be installed and shall be designed and constructed taking into account the environmental conditions, the operational requirements and the safety aspects.

As for the environmental conditions of the installation site, the following factors may affect the life and integrity of materials:

- Minimum and maximum temperature
- Polluting or corrosive substances
- Fouling and/or moulds
- Conditions of the sea bed, including presence of rocks
- Methods of transport and laying
- Depth of installation
- Maximum speed of the currents.

As for the operational side the cables shall be suitable for continuous operation (100% load factor) with short and infrequent over-currents.

As for the safety aspects the design of the submarine cables shall be in full compliance to the existing regulations.

All cables shall be tested in the manufacturer’s workshops during all phases of the manufacturing works with reference to their quality, quantity, dimensions, weight, etc. to prove the suitability of the cables for submarine installation and operation.

Routine tests shall be carried out on each cable length including electrical type tests (measurement of the electrical resistance of conductors, partial discharge test and high voltage test etc).

Special tests shall be carried out on samples of cables including visual examination, cable dimensions (insulation, non-metallic sheaths, armour, external diameter), behaviour of external sheath at low temperature, metal coating of copper wires, bending tests in cold condition, electrical test etc.

Each cable shall be preferably manufactured in a single length not shorter than the requested length. The type of packing in continuous lengths on cable drums or in coils as required for the laying works shall be suitable for overseas transportation and long storage periods at the site environmental conditions.

The two ends of each cable length shall be sealed, fixed to the drum be easily accessible for checks and tests without any need of unwinding the cable.

On the external sheath of the cable there shall be a progressive numbering, at 1 m intervals, for the determination of its length and on the cable drums it shall be labelled at least the vendor’s name, fabrication date, rated voltage U0/U, cable type, core number and conductor cross-section, length of cable on the drum, total mass of cable and drum.

Figure 143 Cable reel

5.3.2 Cables installation.

All the vessels, equipment and materials utilized during transport and installation shall be in accordance with the laws and regulations in force in the country where the operations are carried out.

Before starting any operation it is necessary to verify the bathymetric charts and the information on the seabed conditions along the cables route in order to detect the presence of any rocks or metallic objects that may damage the cable or prevent its good laying on the seabed and the exact position of sea-lines or existing cables to avoid crossovers. The use of divers equipped with cameras and portable magnetometer may assist in this operation. It is also necessary to identify the topographic points for the correct laying of sinkers and buoys, the point on the shore for the positioning of the winch and the configuration and consistency of the landing shore.

Before transport, the cable, wound on a concentric or motorised reel, shall be tested to verify its functionality. After the test the cable heads shall be thoroughly taped to avoid infiltrations during laying. For very long distances the cable may be provided in two or more parts on an equivalent number of reels or in one piece to be loaded and wound in concentric coils on a special vessel.

According to the type of packing of the cable, the necessary equipment and tools shall be made available to load it onto the vessel, transport it and offloading on the laying vessel. The laying operations will require the employment of highly qualified personnel, of a suitable laying vessel, assisted by a support vessels.

The personnel to be employed shall be highly specialised for marine cable operations in open sea and at the landings. Throughout the laying operations they will be assisted by divers for positioning and recovery of floats, laying and control of cables in the riser and in the junction point and laying of cables at the landings.

The laying vessel shall be a self-propelled vessel able to advance at slow speed in order to adjust it to the cable unwinding speed and with a capacity adequate to the load, a shallow draft, a flat deck and anchoring system in order to balance the vessel during operations, winches at the four corners of the vessel, a diesel engine generator and compressor, a crane of adequate capacity for the project besides all the navigational aid systems, rescue means and safety equipments. The specific equipment to allow the laying operations will consist, in case of cable wound on reel, of:

- Reel with or without motor-driven trolley
- Derrick to lift reel
- Conveyor
- Dynamometric unit to control the pulling of the cable

and in case of cables to be wound on the vessel deck

- A-frame pulley
- motor-driven unit with dynamometer, measuring gauges and odometers
- Rollers path
- 1 bow laying skid
- floating balloons for cables, pulling heads, open and closed metallic braidings, equipment for joint assembly and test equipment.

Figure 144 Reel installation on board

The support vessels spread shall be made up of tugboats with adequate power to hold the laying vessel in case of strong transversal winds or currents, vessels supporting divers with equipment adequate to the water depth, motorboats for anchoring and disanchoring the vessel and floating the cable leaving the landing and a vessel for rapid movements of personnel and material between shore/tower/operational vessels.

5.3.3 Laying operations

The laying operations shall start only with a favourable meteo-marine conditions forecast for the whole period of laying after having fixed all the equipment on the laying vessel and completed the preparatory works on the tower, at sea and on shore.
Unwinding the cable on the vessel shall be carried out with extreme care avoiding excessive stresses, keeping a bending and pulling angle within the limits imposed in the specification. Perfect co-ordination between crew aboard the vessel, on the tower and the divers is essential to the success of the operation. Laying shall be carried out with a constant pulling tension avoiding sudden speed variations by the vessel.

Figure 145 Cable laying vessel in operation

The vessel should approach the shore up to the minimum possible distance to limit the quantity of cable to be eased off to sea and pulled to shore.

At the completion of the laying operations, the terminations and connections of cables shall be made by qualified personnel.

The cables shall be buried at a depth between 0.5 and 1 m below the seabed level paying attention at not to damage cables. Eventually, for difficult terrain, the excavator may be equipped with monitors and sensors that will monitor the progress and will indicate in real time the stresses caused to the cable by the excavator ([48.]).

Figure 146 Cable touchdown monitoring

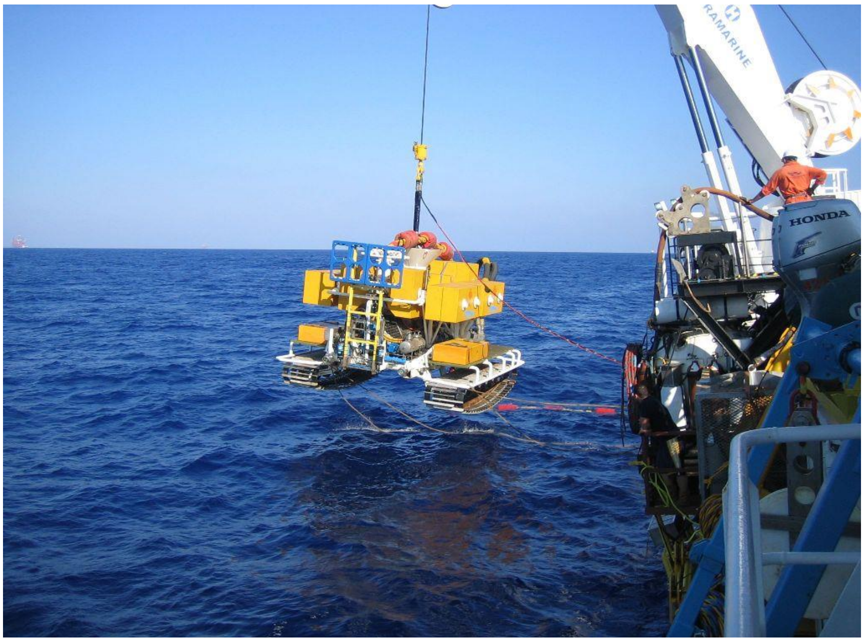


Figure 147 Trenching machine being put in operation

Figure 148 The Capjet Nexan' trenching system for burying submarine cables based on the water jetting principle.

During the execution of the work several tests shall be carried out during the different phases of the operations in order to check the continuity and the good insulation of the cable. The tests shall be executed at the loading phase of the cable onto the vessel, before and after the laying operations and at the completion of the work. They shall consist in the measure of DC electrical resistance of the insulation at 20°C and in a DC voltage test for a duration of 15 minutes according to CEI or IEC normatives.

At the end of the work, it is advisable to carry out a final survey to record the "As laid" installation of the cable that will be included in the final technical documentation

The wind industry's move to deeper waters is challenging because transport vessels can only hold so much cable. Nexans' flagship transport and laying boat, the Skagerrak, holds 50 tons of cable on its built-in turntable (Figure 149). The Skagerrak can accommodate 65 workers and has travelled all over the world. Not many vessels can hold its capacity and there are just one or two others in the world including the Giulio Verne, belonging to Nexans' main competitor Prysmian (Figure 150).

Figure 149 The Nexans Skagerrak: cable laying ship vessel

Figure 150 The Giulio Verne: cable laying ship vessel

With wind farms moving further offshore cable providers are seeking increasingly higher transmission capacity, which means producing larger and longer cables.

Another challenge is that cables are becoming increasingly important in risk management. One of the key differences between offshore and onshore wind farms, at the concept and design phase, is the need to consider cable failure when designing the electrical architecture. Indeed, if a submarine cable fails in service the consequences for the operability and

profitability of the wind farm could be dire; especially if there are delays in securing a suitable repair vessel or if weather conditions are severe, likely during the winter months.
As a consequence, it is essential that the electrical cable systems of wind farms have high reliability.
Another challenge is transport for larger and longer cables.

5.4 Reliability

5.4.1 Theory

The main objective of a reliability study should always be to provide information as a basis for decision [49.].

The results provided by a reliability study will not tell us exactly what to do, but in what direction to look. For example, a reliability study can be useful in areas of risk analysis, optimization of operations and maintenance. The risk analysis is a way of identifying causes and consequences of failure events, and the optimization is a way of telling how failures can be prevented and how to improve the availability of a system. One can see reliability theory as a tool for analysing and improving the availability of the system.

5.4.1.1 Bathtub curve

The failure rate of a component is often high in the initial phase of its lifetime. This can be explained by the fact that there may be undiscovered defects in the components. When the component has survived the initial period, the failure rate stabilizes at a level where it remains

for a certain time until it starts to increase again as the component begin to wear out. The shape of the curve depicting the failure rate of the component, is similar to that of a bathtub, hence the expression bathtub-curve. Figure 151 shows the bathtub curve with the three typical phases. The initial phase is called burn in period, the stable phase is called useful life period and the end phase is called wear out period. Other examples of names for these three periods are break in, operations and breakdown. This terminology varies in literature but the main concept of three different stages in the life of the component or system are still the same.

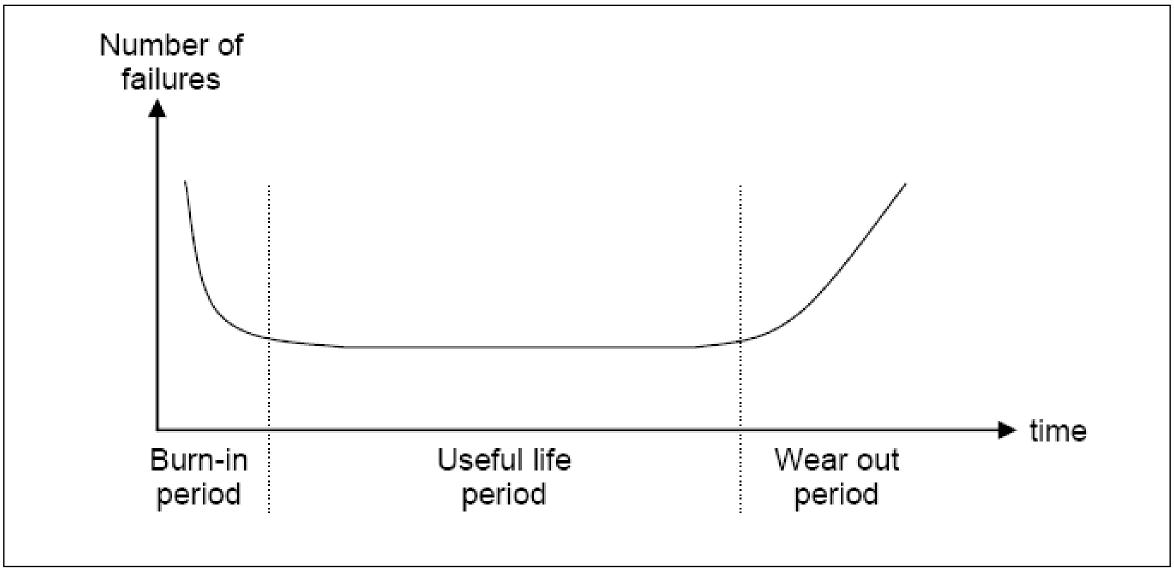


Figure 151 The Bathtub curve

Figure 151 gives one example of a possible shape for the failure function. There are other failure functions with other shapes, but the bathtub curve appears as a good choice for mechanical components such as gearboxes. For the majority of mechanical items the failure rate function will usually show a slightly increasing tendency during the useful life period, because of the wear on the mechanical components.

5.4.1.2 The Alternating Renewal Process

When a component fails, immediate repair is undertaken and when the repair is done, the component is put back into the system and is considered *as good as new*, hence the expression
renewal.

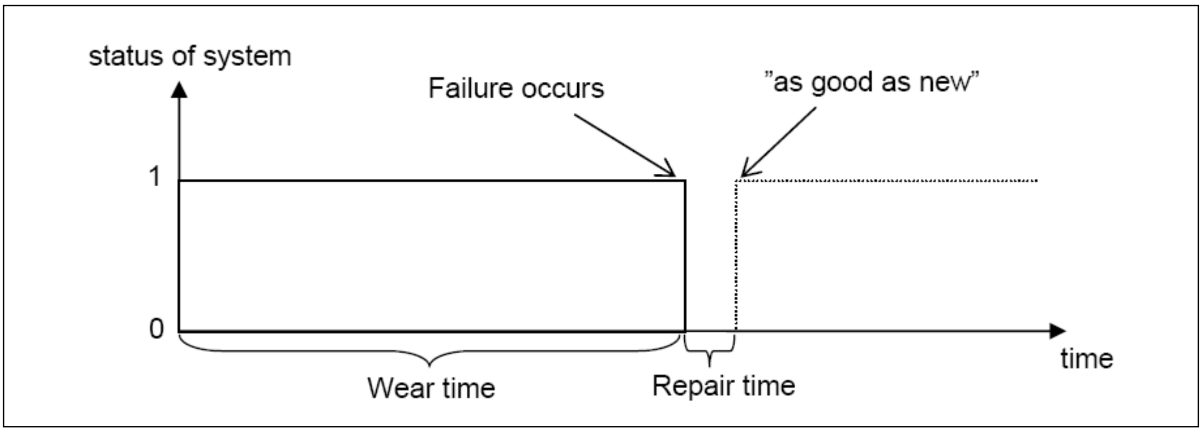


Figure 152 Alternating Renewal process

To be able to understand and to apply theoretical tools to a physical component models are used. One way of modelling the system is by setting it to one of two states: up or down, failure or no failure, see also Figure 152. We can picture the state of the system as a binary process.

It is also possible to look at models with intermediate states between completely new and completely failed. In this type of model, failure is a damage accumulation process [52.], see Figure 153. A model with several states appears suitable for systems with monitoring equipment. The wear model with different stages of deterioration is applicable when analysing specific components where the different stages of wear have been well defined.

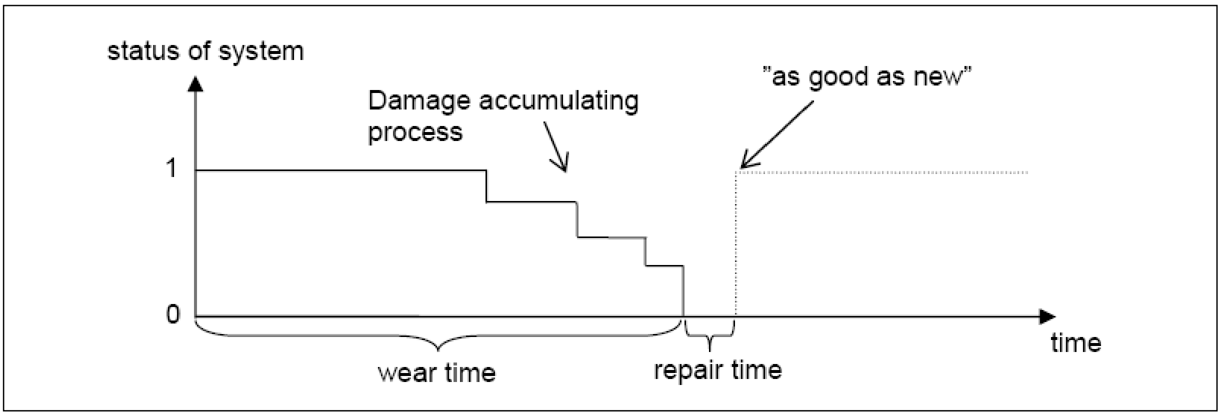


Figure 153 Damage accumulating process

The repair time can be modelled similarly to the lifetime of operations. There is a suitable distribution for repair time, the lognormal distribution, which for example takes into account that some repairs can be made quickly while other repairs rely on spare parts that are not available at the moment. It is also common to use the exponential distribution for repair time. The repair time is of course important when detailed models of the maintenance are considered but it is difficult to find data concerning repair of wind power turbines and yet more difficult to find out the exact amount of time spent on repair. The information that may be available is the amount of time that the system was unavailable, but this time may consist of scheduled maintenance and stoppages caused by other events not connected to any failure.

5.4.1.3 Measurements of reliability performance

The reliability can be measured in many ways depending on the particular situation, for example as: Mean time to failure or number of failures per time unit or failure rate [49.].

The *mean time to failure*, MTTF, is defined as the mean time between initial operation and the first occurrence of a failure or malfunction. When a failure has occurred the item is repaired and put back into operation and the item is then considered as fully functioning.

The *mean down time*, MDT, is defined as the average time that the system is not functioning when a component is being repaired, and is basically the time it takes to repair a failure.

The *mean time between failures*, MTBF, takes into account the mean time to failure and the mean down time. The down time is usually much shorter than the time of operations and then the two measurements can be viewed as: MTTF ≈ MTBF, see Figure 154.

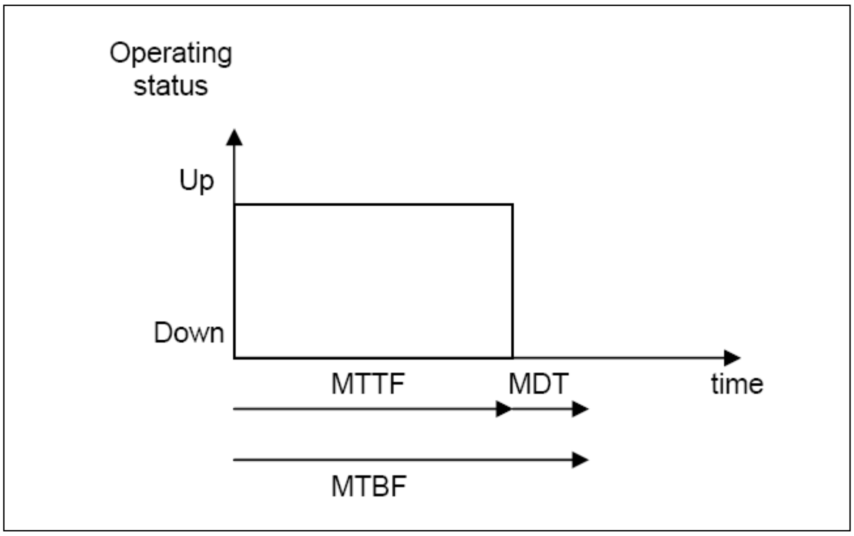


Figure 154 Measurements of reliability

5.4.2 Maintenance methods

Maintenance is required for almost all types of machinery and applies also to the wind power system. The type of maintenance that is performed can be defined as either preventive or corrective maintenance. Preventive maintenance is carried out at predetermined intervals or according to prescribed criteria and is intended to reduce the probability of a failure.

Corrective maintenance is carried out after a failure and is intended to repair the system [50.]. In other words, preventive maintenance is performed before a failure and the corrective is preformed after the failure occurs.

An ideal maintenance strategy meets the requirements of machine availability and operational safety, at minimum cost [53.]. Consequently the challenge in planning the maintenance is to decide on when to perform preventive maintenance.

In this chapter an explanation of three different methods for maintenance is presented: corrective maintenance and two types of preventive maintenance; scheduled maintenance and condition based maintenance, see Figure 155.

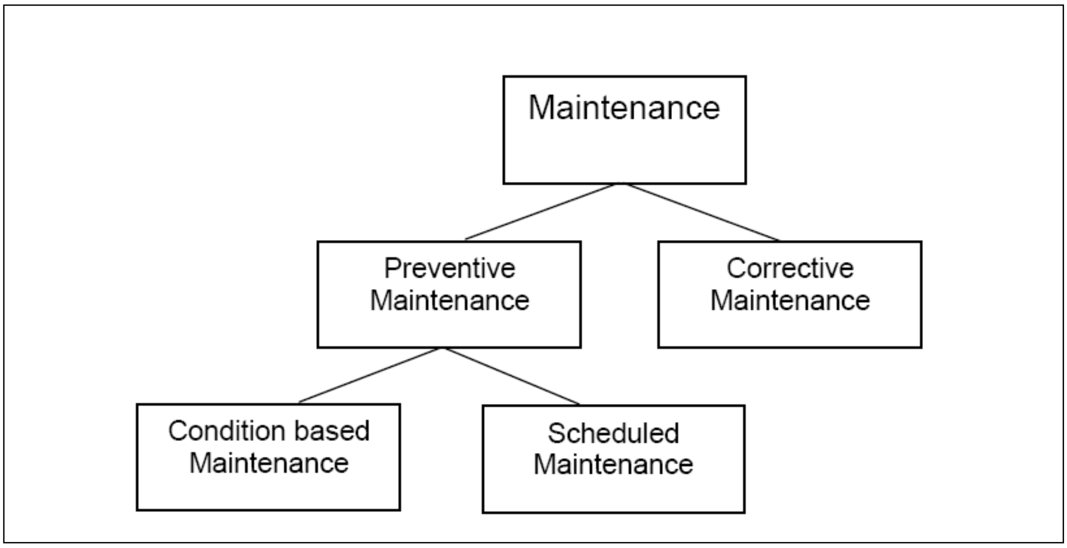


Figure 155 Classification of maintenance types

5.4.2.1 Corrective maintenance

Corrective maintenance is defined as "*the maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function*".

This type of maintenance is often called repair and is carried out after the failure of a component. The purpose of the corrective maintenance is to bring the component back in to a functioning state as soon as possible, either by repairing or replacing the failed component [52.].

Utilizing only corrective maintenance is seldom a good solution. This means that the system will run until a breakdown occurs and in some literature this is referred to as a *breakdown strategy* [53.].

With a breakdown strategy the preventive maintenance is reduced to a minimum and the system will be operated until a major failure of a component occurs which will result in a shutdown of the wind turbine. This strategy is risky, since failures of relative small and dispensable components can lead to severe consequential damages. Another aspect of such a strategy is that most component failures are likely to be related to the actual load condition of the wind turbine and is also likely to happen during high load conditions. This means that the shutdown of the turbine is related to high wind periods. Downtime in such periods will lead to higher production loss. If the wind turbine is situated offshore, the accessibility is likely to be bad during high wind periods [53.].

Another drawback of this strategy is that when repair is needed the downtime can be extensive since logistics gets more complicated and delivery periods for spare parts can be long. A breakdown strategy minimizes the cost for repair and maintenance during operation. With no knowledge of the consequence of a failure until it occurs makes it impossible to calculate the costs of replacements. The lifetime of the component is unpredictable and only once the component has failed an assessment of the cost and lifetime can be made [53.].

5.4.2.2 Preventive maintenance

Preventive maintenance is defined as the maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of functioning of an item [50.].

The preventive maintenance is performed regularly to postpone failures or to prevent failures

from occurring. There are two different types of preventive maintenance: the scheduled maintenance and the condition based maintenance. What differs between these two are the way of deciding when to perform the preventive maintenance.

<u>Scheduled maintenance</u>

Scheduled maintenance is carried out in accordance with an established time schedule [50.].

The time-schedule for the preventive maintenance can be either *clock-based* or *age-based maintenance*. Clock-based maintenance means that the preventive maintenance is carried out at specified calendar times and age-based maintenance means that the maintenance is carried out when a component reach a certain age. The age does not need to be calendar time, but measured in for example revolutions or operational time etc [49.].

Preventive maintenance performed at scheduled intervals should be designed to reduce the probability of failures. Maintenance cycle times will be matched to the requirements of the system. The system will be inspected and maintained periodically, see Figure 156.

The components that first show sign of wear and fatigue will be maintained and replaced. This type of maintenance strategy means that components exposed to wear will be replaced regularly even if they are not at the end of their lifetime.

Scheduled maintenance requires regular access to the system and a big share of the costs for the maintenance will stem from the supply for cranes and maintenance personnel. Transport of personnel and spare parts to the wind farm can also be cost intensive with this preventive maintenance strategy. The main advantage of preventive maintenance is that it can be scheduled ahead of time and the coordination of logistics can be made easy [53.].

Figure 156 shows a comparison between Corrective Maintenance and Scheduled Preventive Maintenance.

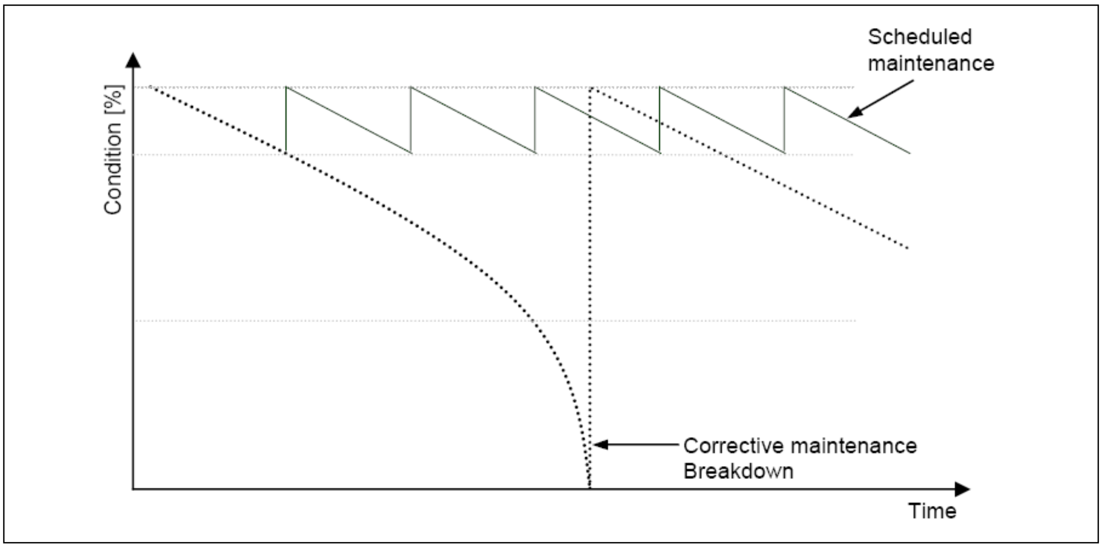


Figure 156 Corrective Maintenance compared to Scheduled Preventive Maintenance

Condition based maintenance

Condition based maintenance is a type of preventive maintenance that is based on the performance and monitoring of parameters from the system. With this type of preventive maintenance, monitoring equipment collects machine data. The condition monitoring may be scheduled, on request or continuous [50.]. The collected machine data can indicate required maintenance prior to predicted failure. Maintenance is initiated when a condition variable approaches or passes a threshold value. The system components will be operated to a defined condition of wear and fatigue. When this condition is reached, the component needs to be maintained or replaced [53.]. Examples of condition variables that the system monitors are vibration, temperature, number of particles in the lube oil etc.

The ability to monitor the condition of components facilitates planning of maintenance prior to failure and will minimize downtime and repair costs. The components will be used closer to their lifetimes and the coordination of spare parts will be easy. Another benefit of implementing a condition based system is that trends and statistical data such as mean time to failure can be provided [53.]. The statistical data from monitoring system is important for getting reliable data for remaining lifetime of components in the system. With site specific data the prediction of remaining time for the components can be more precise.

Figure 157 shows an example of condition based maintenance along with corrective and scheduled maintenance.

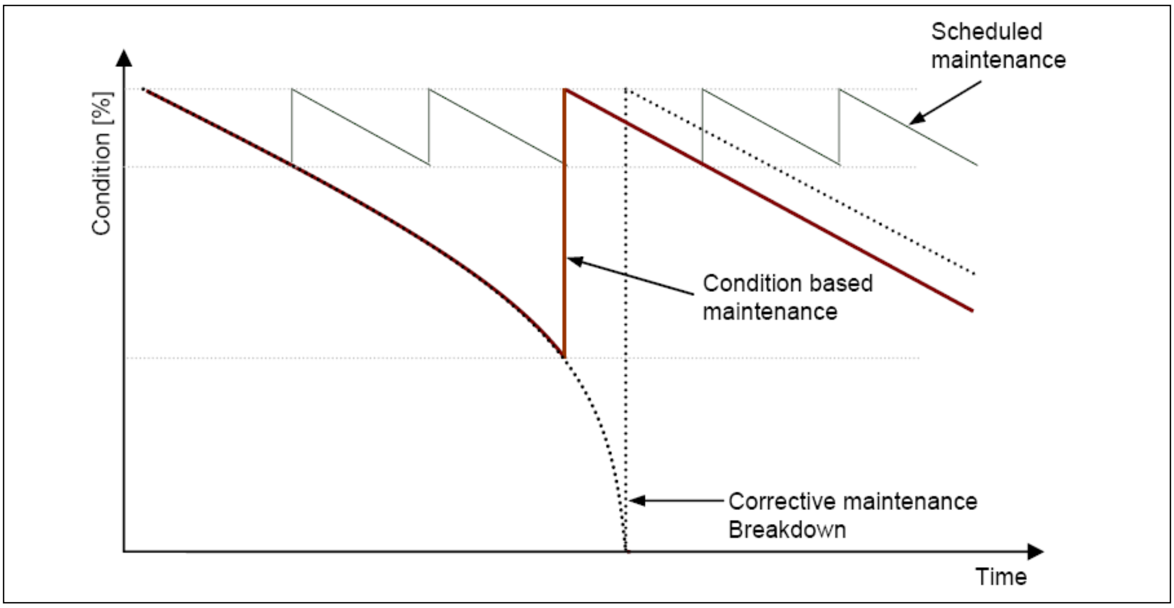


Figure 157 Condition based maintenance compared to scheduled and corrective maintenance

5.4.2.3 Comparison of maintenance methods

Figure 157 shows a graphical example of possible scenarios for maintenance. The comparison shows that scheduled maintenance is performed more often than condition based maintenance. The example also shows that the lifetime of the component is not fully used in the scheduled maintenance compared to the use of corrective or condition based maintenance.

Table 1 shows some advantages and disadvantages found for the different maintenance methods when applied to wind power.

Table 10 - Comparison of maintenance methods ([51.][53.])

Method	Advantage	Disadvantage
Corrective Maintenance	• Low maintenance costs during operation • Components will be used for a maximum lifetime	• High risk in consequential damages resulting in extensive downtimes • No maintenance scheduling is possible • Spare parts logistics is complicated • Long delivery periods for parts are likely
Preventive Maintenance - Scheduled	• Expected downtime is low • Maintenance can be scheduled • Spare logistics is easy	• Components will not be used for maximum lifetime • Maintenance costs are higher compared to corrective maintenance
Preventive Maintenance - Condition based	• Components will be used up to almost their full lifetimes • Expected downtime is low • Maintenance activities can be scheduled • Spare part logistics is easy given that a failure can be detected early in time	• Reliable information about the remaining lifetime of the components is required • High effort for condition monitoring hardware and software is required • Cost of another layer in the system • Not a mature market for monitoring systems within wind power • Identification of appropriate condition threshold-values is difficult

5.4.2.4 Maintenance strategy

With the three methods presented a maintenance strategy can be implemented. The strategy will be a combination of preventive and corrective maintenance. The use of condition monitoring equipment makes the condition based maintenance a good option as to reduce cost related to maintenance. Logistics can be planned ahead and the lifetime of the components can be almost completely utilized.

A condition monitoring programme can minimize unscheduled breakdowns of all mechanical equipment and ensure that repaired equipment is in an acceptable mechanical condition. The programme can also identify machine train problems before they become serious [51.].

5.4.3 Survey of failures for wind power turbines

Modern wind turbines achieve a quite high availability of about 95% to 99%. Nevertheless, quite a number of faults cause unscheduled down times up to ten per year, resulting in high maintenance efforts, production losses and costs.

Hereafter are described new approaches for condition monitoring, fault prediction and operation & maintenance (O&M) strategies into the wind turbines for offshore wind farms. The knowledge of frequent failures or typical failures related to certain wind turbine tipologies is an important basis for the wind turbines reliability improvement and the development of appropriate condition monitoring ([54.]).

5.4.3.1 Source of information

The Fraunhofer IWES (Institute for Wind Energy and Energy System Technology) has gathered operational experience from wind turbines since 1989 and is involved in different projects dealing with the topic of availability and reliability. IWES's database was established within a long-term German research programme: the "Scientific Measurement and Evaluation Programme" (WMEP), funded by the "250MW Wind" project in Germany. Owners or operators of wind turbines, receiving funding from government, were obliged to report on energy yields, on operational cost and on all maintenance measures. In the period of 17 years 64.000 maintenance & repair reports (shown in Figure 158) from over 1500 wind turbines were fed into a database at IWES. This database is called WMEP database.

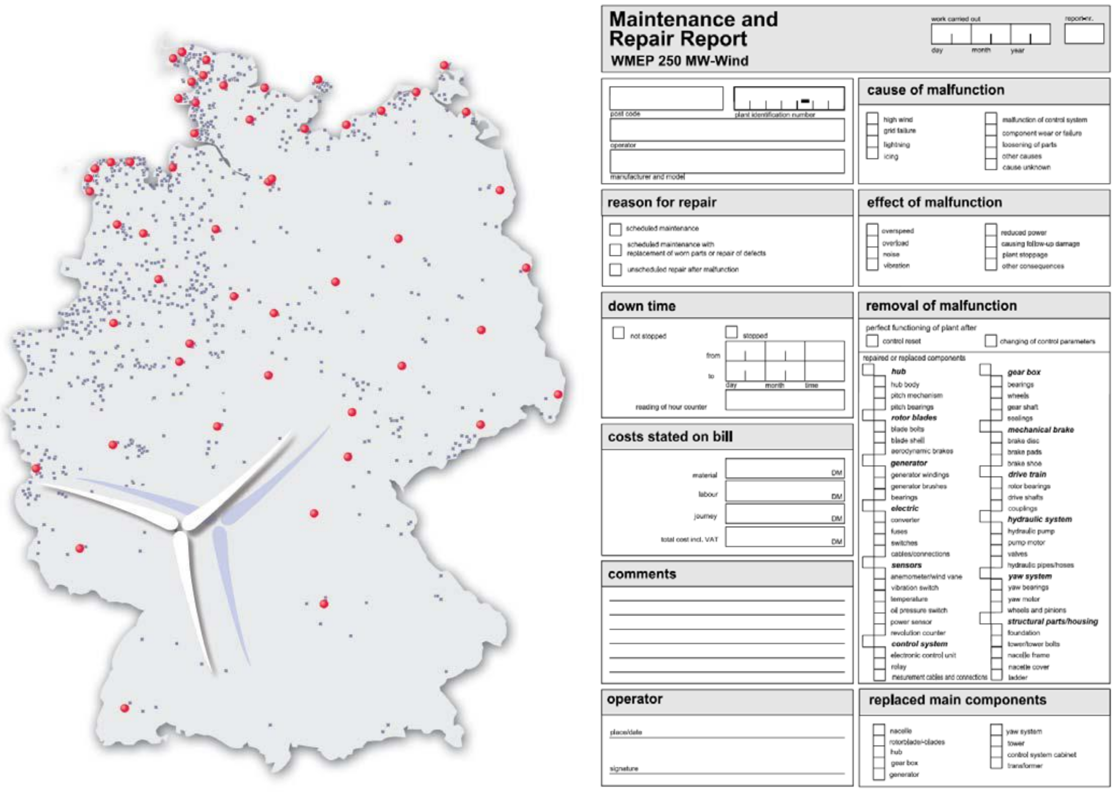


Figure 158 Wind turbines in the WMEP (left) and maintenance report (right)

The WMEP database contains a quantity of detailed information about reliability and availability of wind turbines and subassemblies and provides the most comprehensive study of the long-term behaviour of WTs worldwide and the most reliable characteristic values concerning reliability ([54.]).

5.4.3.2 Methodology

Numerous parameters are important to describe the availability of wind turbines and should therefore be considered in an appropriate reliability analysis. Therefore, in the first step a selection of turbines and the influencing parameters have to be made.

In the second step the reliability characteristics are calculated for each single turbine and average values are determined.

Based on these results an overview of components with the highest mean annual downtimes can be presented and the most frequent failures are investigated. To determine failures, which are likely to be detected in advance through a condition monitoring system, a selection of gaugeable failure causes is made in the next step.

An overview about the methodology for the investigations is shown in Figure 159.

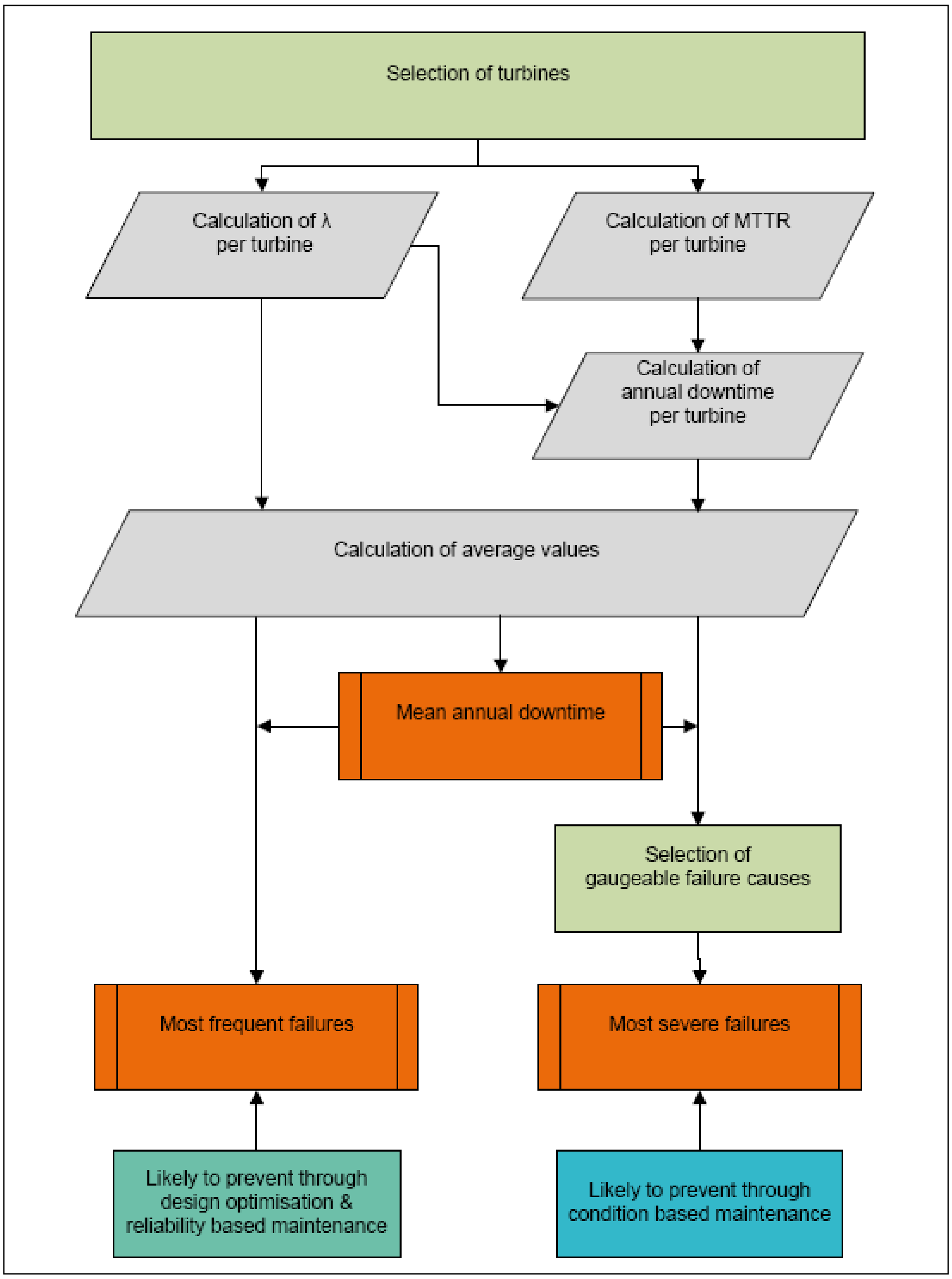


Figure 159 Methodology of investigations

1. Selection of turbines

The reliability of wind turbines is of course strongly dependent on the wind turbine in use. An example can be found in the size of wind turbines. Besides the size, the technical concept of the wind turbine is a very important influencing parameter regarding reliability.

The continuous expansion of wind energy use has enabled manufacturers to make enormous technical progress. But while the performance and efficiency of wind turbines and hence the energy yields have been continuously improved, there is still a significant need for optimising the reliability of wind turbines. In the following the evolution of technology will be illustrated by three different technical concepts. To allow a comparative analysis, the different wind turbines are classified in three groups of concepts. An overview of the characteristic features of the concepts is given in the table below.

Table 11 - Features of the technical concepts

	I	II	III
	Simple Danish concept	Advanced Danish concept	Variable-speed concept
Exemplary turbine groups	AN Bonus 100/150 Vestas V 17/20	Vestas V 25/27/29 Ventis 20-100	Vestas V 63/66 Enercon E 66
Control	Stall	Pitch	
Speed characteristic	constant		variable

Besides technical concepts there are more parameters which should be considered in an appropriate reliability analysis.

An important variable can be described by the time dependency. The principal development of failure rates with time of operation is well known in other technical areas. Another time dependent influence comes from the maturity of the turbine model. It is of importance whether a turbine model has been built since several years or a new concept has been developed.

The influence of operational conditions, e.g. wind speed, is also important to indicate the reliability characteristics of wind turbines.

2. Calculation of Reliability characteristics per turbine

Some general definitions of the variables taken into account for reliability assessment are described in the following.

Annual Failure rate (λ)

The failure rate λ is the reciprocal of the MTBF (Mean time between failures). It is calculated for each turbine using Equation 1

Equation 1

$$\lambda = \frac{\Sigma n}{T}$$

in which n is the number of failures and T is the nominal time, that is the actual calendar time.

Mean time to repair (MTTR)

The Mean time to repair is the average time that a subassembly will take to recover from any failure. It is calculated using Equation 2.

Equation 2

$$MTTR = \frac{T_{Downtime}}{\Sigma n}$$

in which $T_{Downtime}$ is the 'non-available time' made up of a scheduled part (maintenance jobs) and an unscheduled part (breakdowns and damage).

Annual downtime (ADT)

The annual downtime refers to periods when the wind turbine is unavailable. It can be calculated as the product of the reliability characteristics described above as shown in Equation 3.

Equation 3

$$ADT = \lambda \cdot MTTR$$

3. Calculation of average values

All wind turbine types were characterized and grouped by a set of parameters. To calculate the reliability characteristics, the appropriate values were determined for each wind turbine type individually and afterwards aggregated to the typical value of the group of turbines considered.

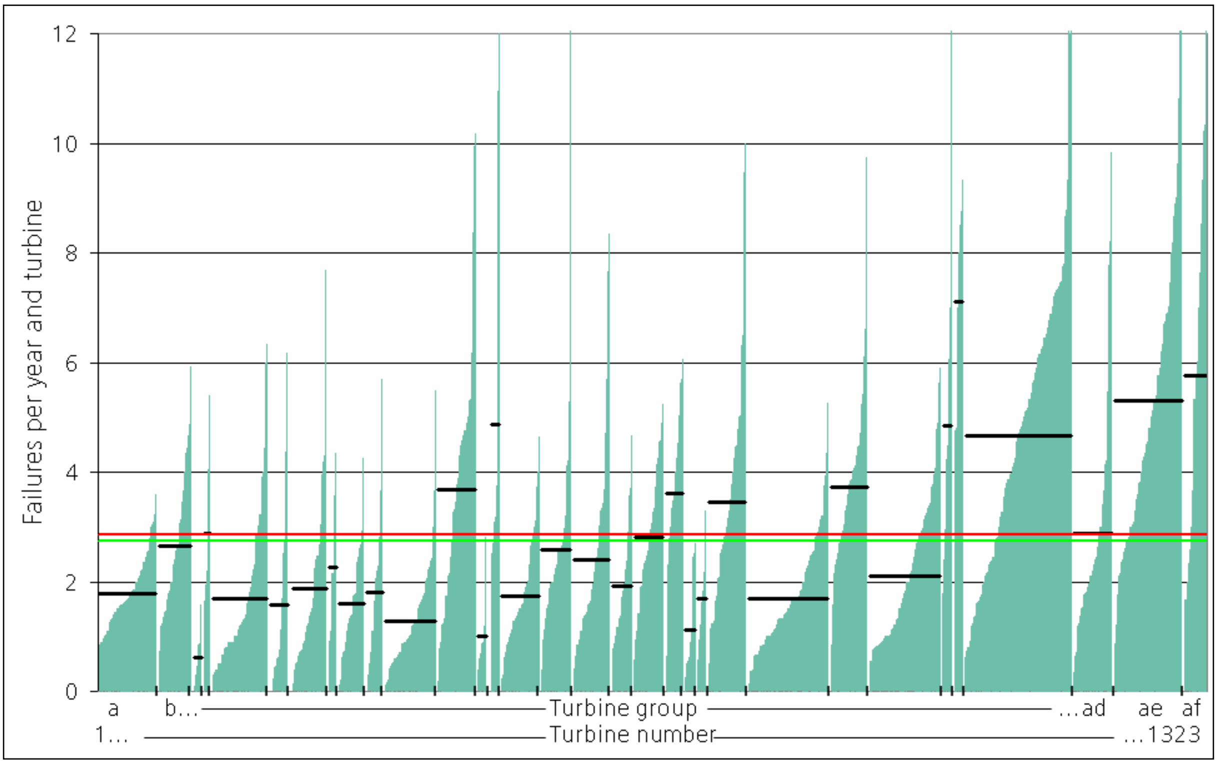


Figure 160 Comparison of mean annual failure rates

The figure shows the annual failure rate for each single turbine in the WMEP-database as a single vertical bar (because of the large number they do appear as continuous areas for each turbine group rather than as single bars). All individual turbines of the same type are aggregated to turbine groups (e.g. Vestas V 25/27/29 is one group, Vestas V 63/66 another). Additionally, they are sorted according to their turbine reliability, the turbine with the lowest failure rate on the left of the group, the one with the highest failure rate on the right. The average values for the different turbine groups are illustrated as black horizontal lines.

The average value for the whole population of turbines in the WMEP (average for all vertical bars), shown by the red line, is slightly higher than the average value for the turbine groups (average of the black horizontal lines), illustrated by the green line.

4. Selection of failure causes

Besides knowing which subassembly is affected, the WMEP also gives the possibility for a Root Cause Analysis since the failure causes are stated in the incident reports. Figure 161 gives an overview of all failure causes for each individual turbine.

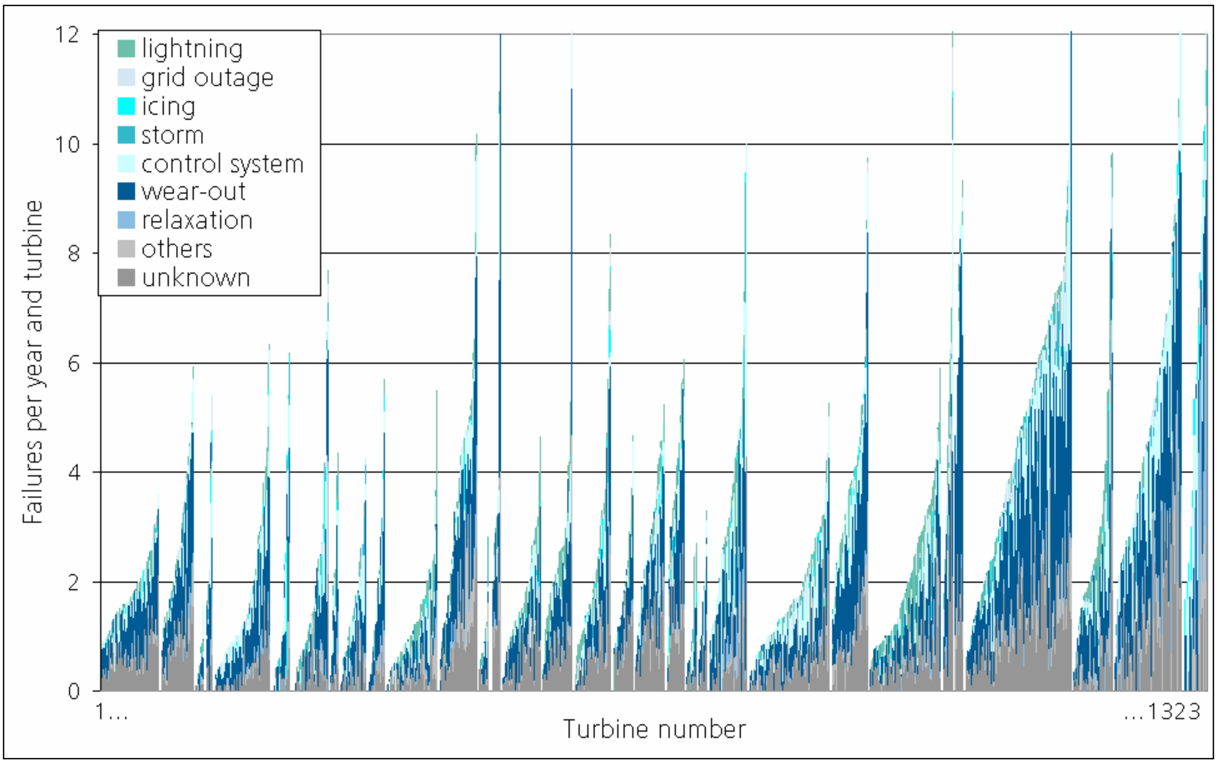


Figure 161 Failure causes for single turbines

The failure causes are more or less miscellaneous, but in most cases of turbine shut down wear out has been the failure cause. In less than a quarter of all cases the faults were caused by external influences. Furthermore, storms, lightning, ice accretion or grid outages mostly affect electrical subassemblies rather than mechanical ones.

Figure 162 depicts the results for electrical subassemblies (left side) compared to some “large” components, such as drive train or gear shaft (right side).

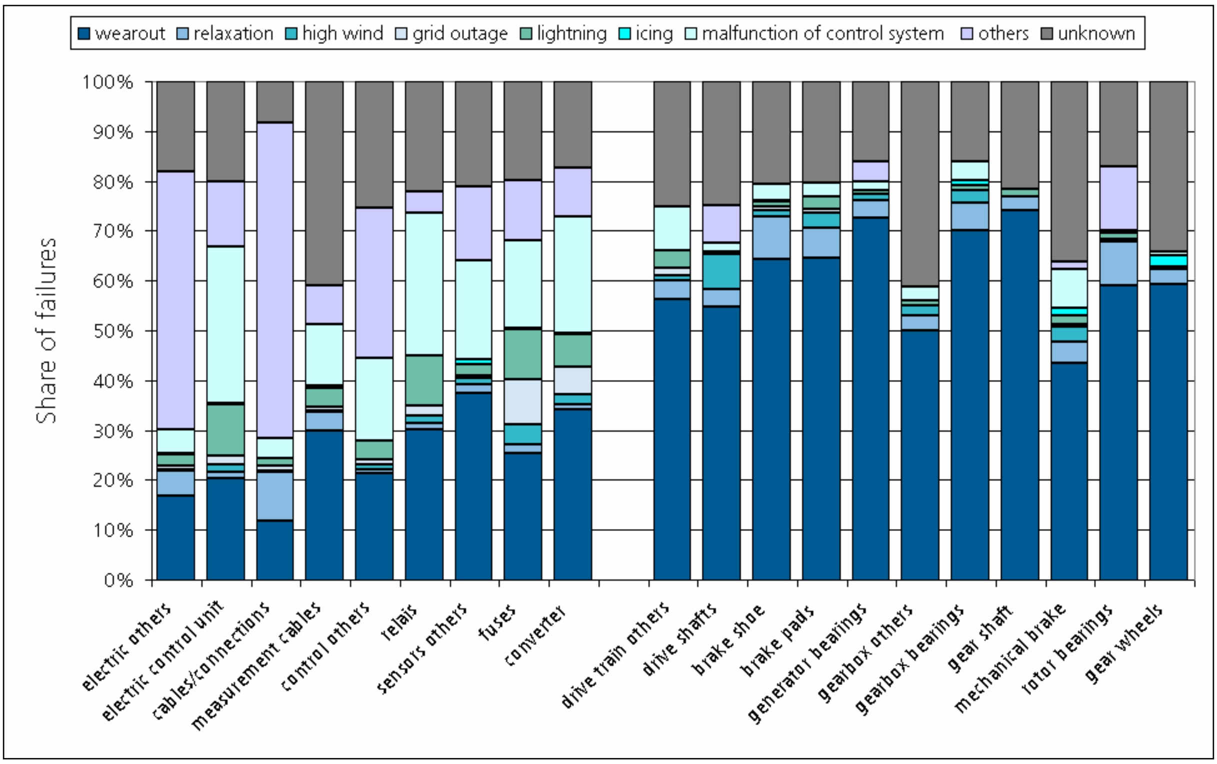


Figure 162 Failure causes for different components

It can be seen that the failures of large mechanical components are more likely due to wear out while the failures of the electrical subassemblies show numerous failure modes. Even though, deterioration for the electrical subassemblies may be important too.

Nevertheless, in most instances the external causes and the following failures are difficult to predict and are more likely to prevent by design optimisation or safety measures. However, for doing so deep knowledge about different failure modes is needed.

Ultimately, failure causes can be divided in three groups, according to frequency and severity of failures (see Table 12). The frequent failures which can often not be detected in advance and are more likely to prevent through design optimization. The severety failures, which are dominated by unexpected wear out, are therefore more or less predictable by sophisticated condition monitoring systems. Finally, failure causes which are often stated as unknown or others due to insufficient documentation, which makes an appropriated prevention more difficult.

Table 12 - Failure causes and the possibilities for preventing

Failure cause	Likely to prevent through
Lightning	Design optimisation
Grid outage	
Malfunction of control system	
Icing	
Storm	
Wearout	Condition based maintenance
Relaxation	
Others	Unknown
Unknown	

6 Analysis of disused offshore platforms to install the weather stations

6.1 Disused off-shore platforms requirements to house the weather station

The meteorological towers designed for the offshore installation are typically self-supporting lattice steel towers. On the lattice there are at least 3 levels of sensors supported by horizontal steel arms. The wind load acting on various instruments and their rods is usually negligible. Since there are no wind-bracings, these towers can be placed on a rather limited area (within approximately **50 m^2** at the base). Possible tower height can be from **60** to **100** meters.

The met mast of the Egmond aan Zee (Oland) wind farm is a typical example of an offshore – placed meteorological tower. It is a rectangular section 106 meters tall tower (support platform not included). The section maximum side (at tower base) is 7 meters, that means a rectangular footprint of about **20 m^2 [55.]**.

Figure 163 The 106 meters meteorological tower of the Egmond aan Zee (Mierij Meteo) wind farm. Bottom right figure the PV panels who supply the three levels of instruments [55.].

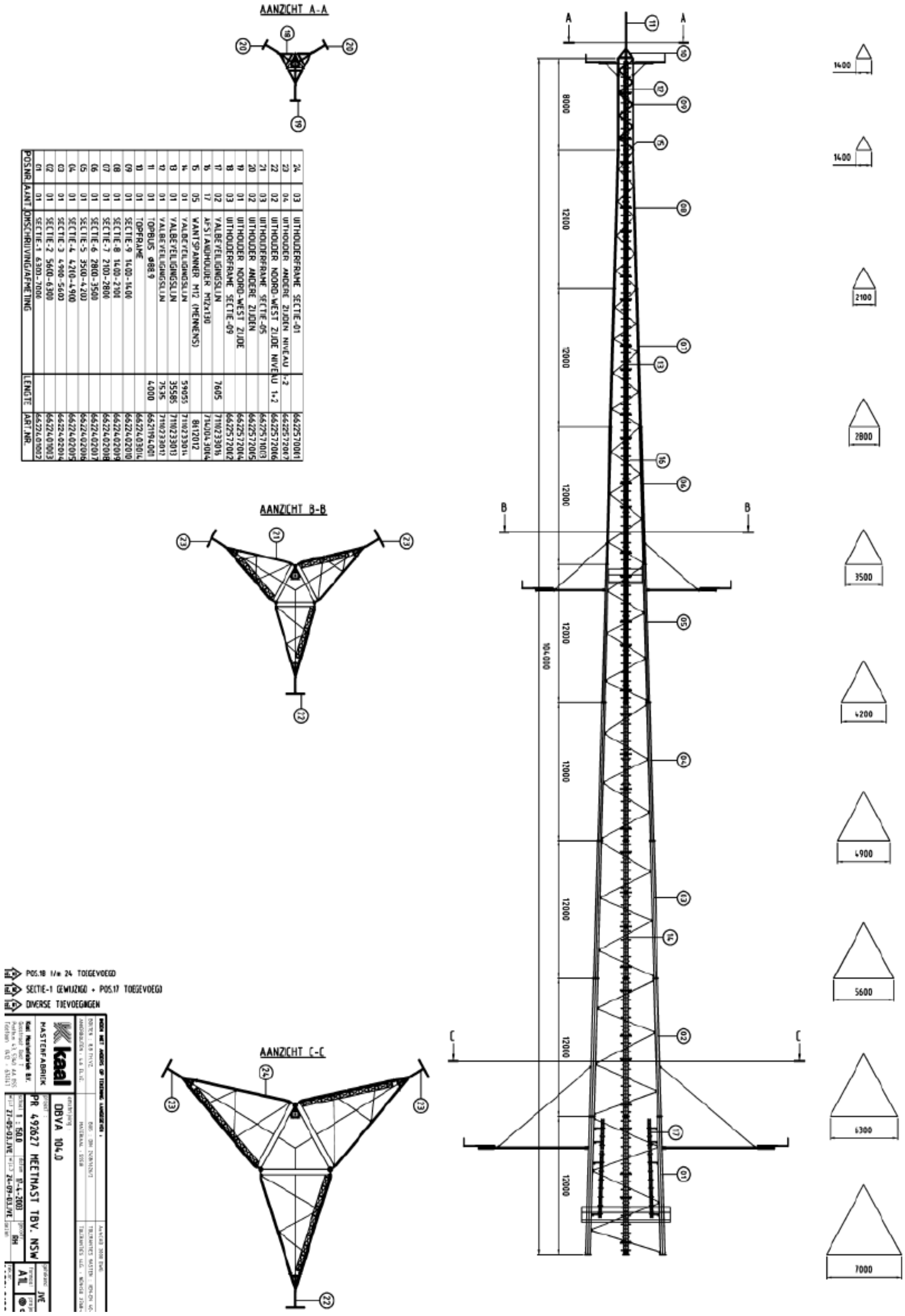


Figure 164. Egmond aan Zee wind tower: lattice scheme. The section side goes from 7 meters (at the base) to 1,6 meters (at 106 meters above ground level) [55.].

To give an idea of the design loads for the anchorage of a similar tower to a support platform, a calculation of the overturning moment generated by the wind acting on the truss is shown.

According to NTC2008 standards [56.], is assumed to be in "zone 9" and exposure category "I", that is related to the characteristic offshore wind. Therefore are used a basic reference wind speed of 31 m/s and the following exposure parameters:

Table 13. Parameters used for the exposure coefficient (according to [56.])

k_r	0.17
z_0	0.01
z_{min}	2

Taking into account the aeroelastic phenomena on design process, there is a payback period of the structure of 10x50 = 500 years (10 times the 50 years nominal life of the structure). This leads to a reference speed of 20% larger than the design one: v_r = 1,207x31 = 37,4 m/s. Adopting a logarithmic law for the speed vertical profile, the following trends in average speed and kinetic pressure peak at the reference wind speed were obtained.

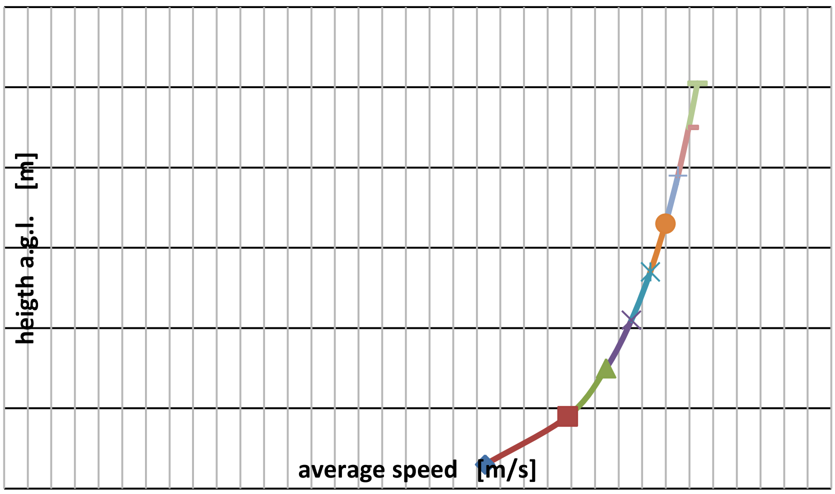


Figure 165. Average kinetic pressure peak vertical profiles.

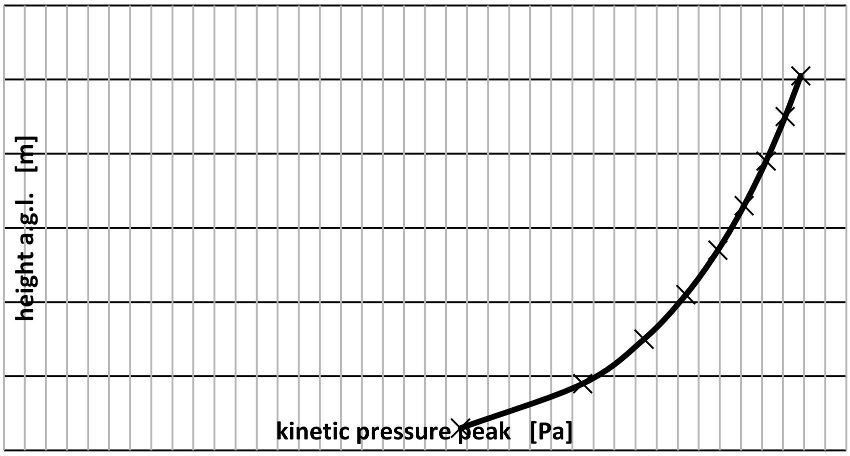


Figure 166. Average kinetic pressure peak vertical profiles.

This wind, acting on the tower, generates horizontal thrust that is related to the lattice drag coefficient C_F. It is assumed that the lattice is made of circular rods and the solidity ratio ϕ is 0.2. Using the following graphs, a C_F of 1,48 is fixed: the wind facing the triangle bisector appears to be more burdensome.

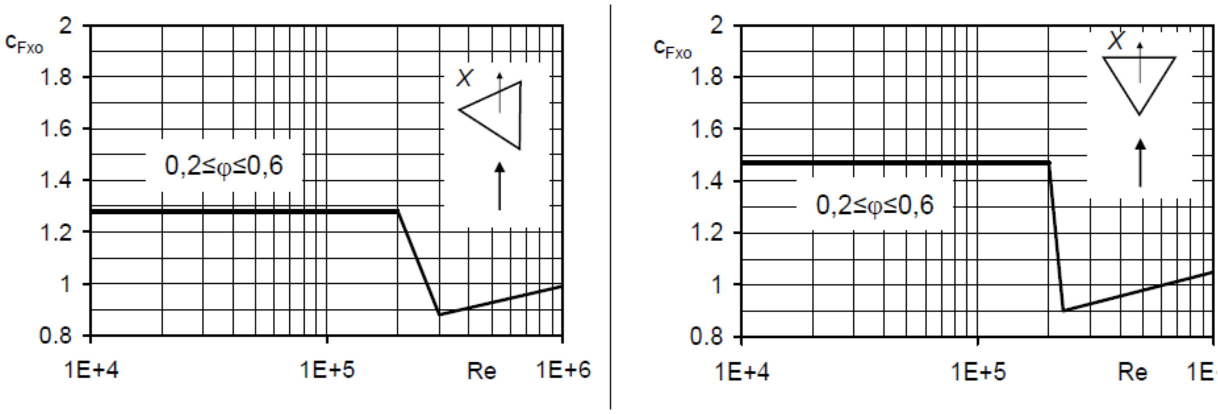


Figure 167. Drag coefficient for rectangular section lattice towers made of circular rods. Right figure is the worst wind direction. (Source: Figure G.45, [57.])

Given a tower of the 106 meters high like the Egmond aan Zee one, according to the taper shown in Figure 168, is calculated the horizontal thrust Fx given by the wind on the different sections in which the tower is divided.

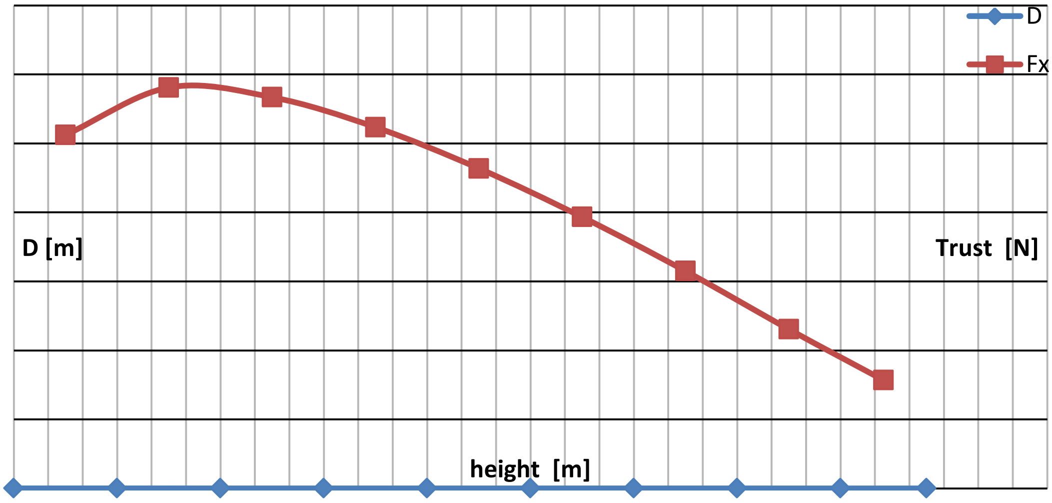


Figure 168. Section width D and maximum wind thrust Fx trends along the tower height.

This force distribution creates a overturning moment at the base of about **16,5 MNm**. Adding only the contributions up to 60 meters there is a moment load of about **7,8 MNm**: This value is representative for a tower 60 meters high but as wide as the 106 meters one. Thus **7,8 MNm** is a overestimated value for a normal tower of 60 meters high.

Coming back to the 106 meters high tower, the maximum moment load of **16,5 MNm** gives on each bearing pile (at 7 meters from each other in the base section) an axial stress of about **2 MN**, able to yield a Fe510 steel tube of 46 cm diameter and 4 mm thickness. This stress should be superimposed to the tower self weight.

Another example of a self-supporting meteorological lattice tower fixed on ground (onshore) is shown in the following figure.

In appendix B are reported the disused offshore platforms of the Adriatic Sea and their characteristics, such as general data, dimensions and sites information.

Figure 169. An example of self-supporting meteorological lattice tower fixed on ground (Calzavara SpA, [58.]).

7 Summary and Conclusion

The POWERED project - "Offshore Wind Energy: Research, Experimentation, Development" is aimed to define common strategies and methods for the offshore wind energy development in all countries bordering the Adriatic Sea.

This report is part of the WP3 - "Technological, normative, of energetic and environmental policies state of the art" and concerns the Task 3.1 - "Technological state of the art". The report provides an overview of the main offshore wind energy technologies and design criteria that are significant for the future development of offshore projects in the Adriatic sea.

Firstly an **OVERVIEW OF THE OFFSHORE WIND ENERGY** has been carried out focusing on the current state, on the offshore wind energy scenarios for 2020 and 2030, on the production and constructive trends and on the advantages and drawbacks.

Annual wind power installations in the EU have increased steadily over the past 3 years from 9.3 GW in 2010 to 11,159 GW in 2013 (Figure 170). Of the 11,159 MW installed in the EU, 9,592 MW were onshore and 1,567 MW offshore. In 2013, the onshore market decreased in the EU by 12%, whilst offshore installations grew by 34% (Figure 171). Overall, the wind energy market decreased by 8% compared to 2012 installations.

The EWEA's (European Wind Energy Association) scenarios show that wind energy **in 2020 should meet 15.7%** of EU electricity demand from an installed capacity of 230 GW, and by 2030, 28.5% from an installed capacity of 400 GW. Indeed, EWEA believes wind energy can provide **half of Europe's power by 2050**, with the remainder from other renewable sources.

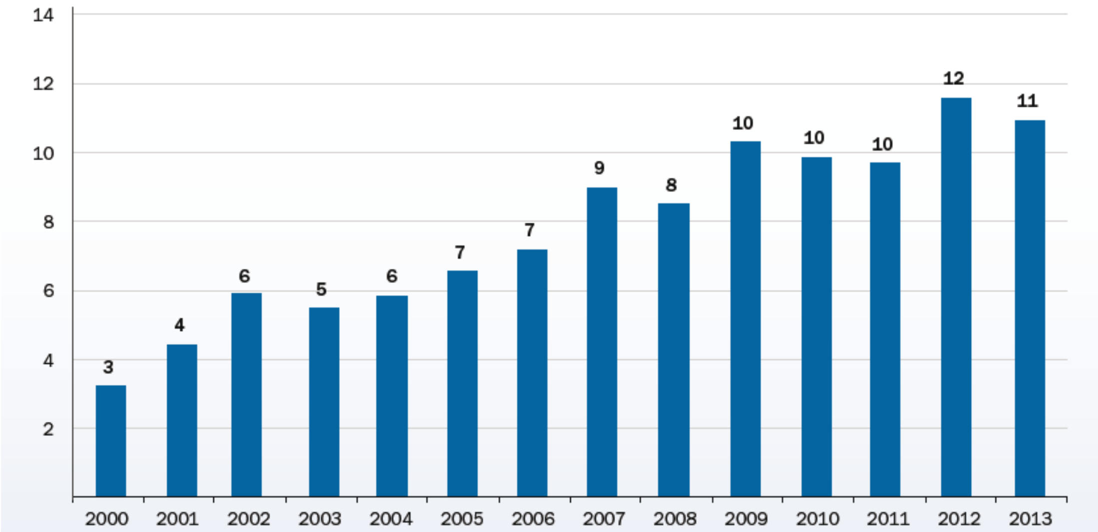


Figure 170 Annual wind power installations in EU (GW) – EWEA 2014

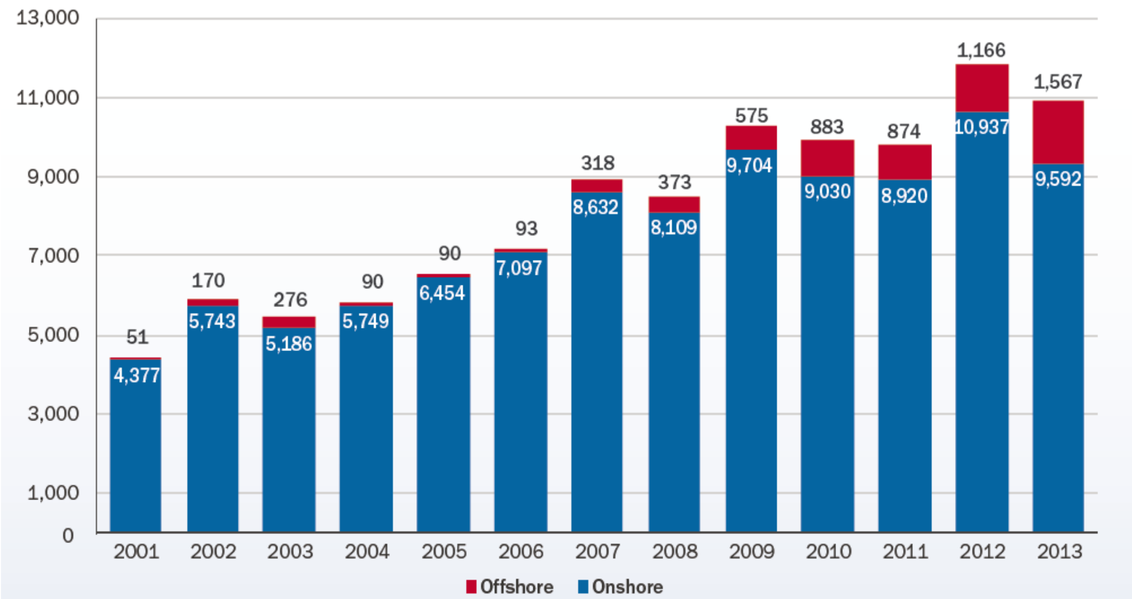


Figure 171 Annual onshore and offshore installations (MW) – EWEA 2014

In terms of annual installations, 46% of all new EU installations in 2013 were in Germany and the Uk, a significant concentration compared to the trend of previous years when installations were increasingly spread across Europe (Figure 172).

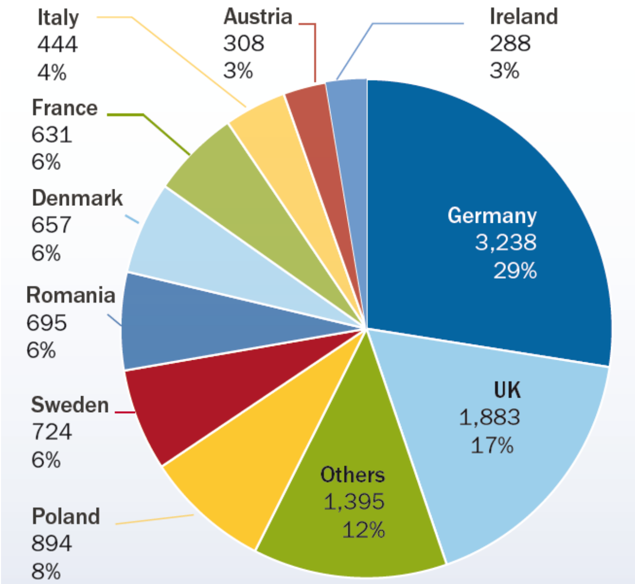


Figure 172 EU member state market shares for new capacity installed during 2013 in MW – EWEA 2014

At end 2013, a total of 117 GW is installed in the European Union with a growth of 10% on the previous year and lower to the growth recorded in 2012 (Figure 173).

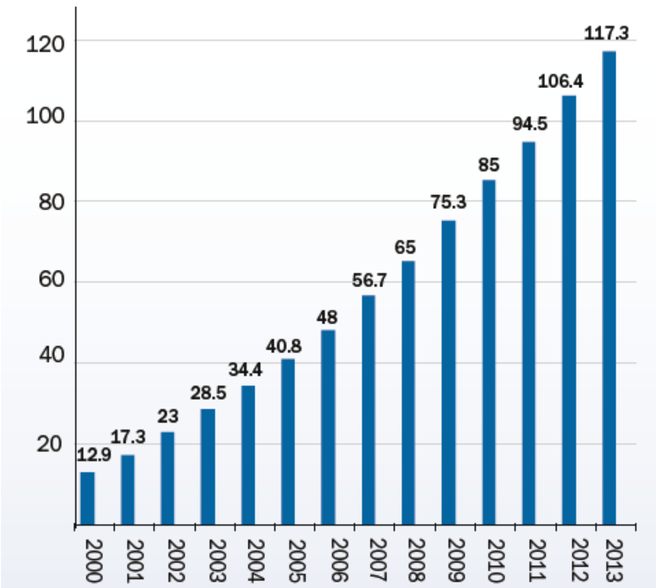


Figure 173 Cumulative wind power installations in the EU (GW) – EWEA 2014

Germany and Spain have the largest cumulative installed wind energy capacity in Europe, follow the UK, Italy and France. Amongst the newer Member States, Poland is now in the top 10, in front of the Netherlands and Romania (Figure 174).

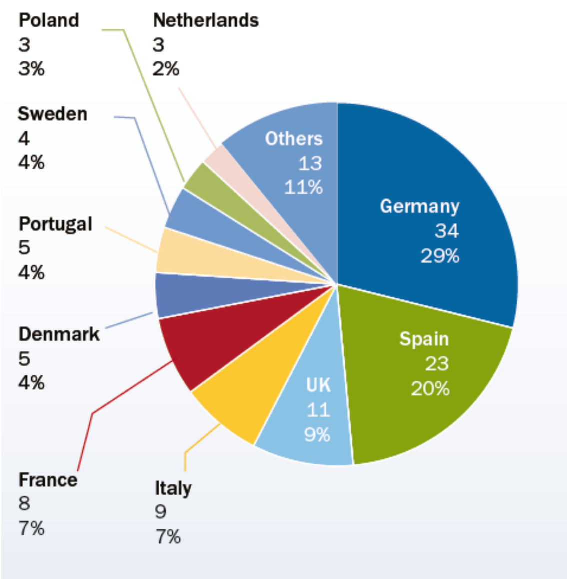
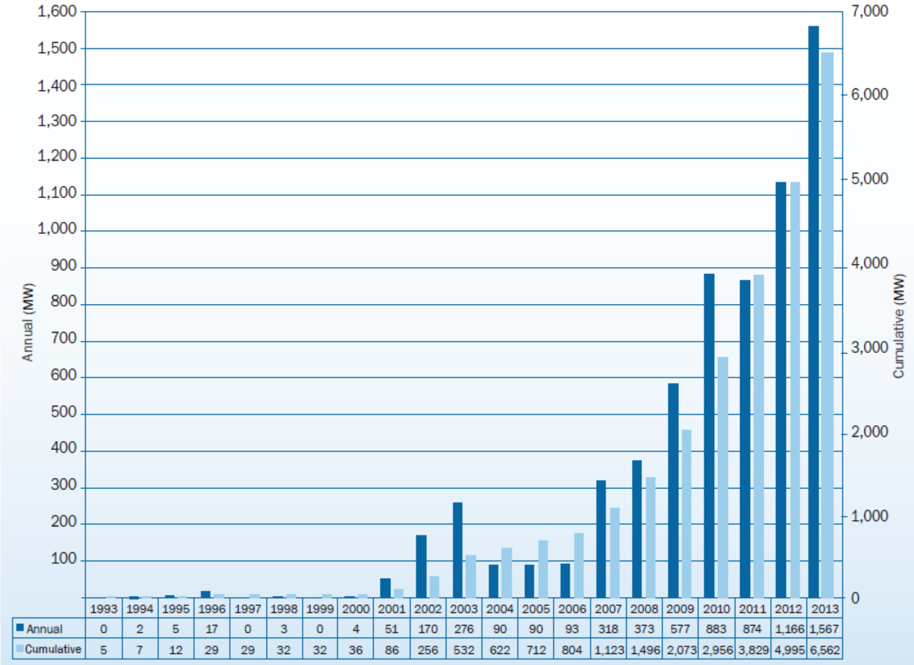


Figure 174 EU member state market shares for total installed capacity (GW) – EWEA 2014

With regard the **offshore market**, during 2013 in Europe 1,567 MW of new offshore wind power capacity were connected to the electricity grid. Total installed capacity at the end of 2013 reached 6,562 MW producing 24 TWh in a normal wind year, enough to cover 0.7% of the EU's total electricity consumption (Figure 175).



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Annual	0	2	5	17	0	3	0	4	51	170	276	90	90	93	318	373	577	883	874	1,166	1,567
Cumulative	5	7	12	29	29	32	32	36	86	256	532	622	712	804	1,123	1,496	2,073	2,956	3,829	4,995	6,562

Figure 175 Cumulative and annual offshore wind installations (MW) – EWEA 2014

The largest amount was installed in the UK, followed by Denmark , Germany and Belgium as showed in Figure 176.

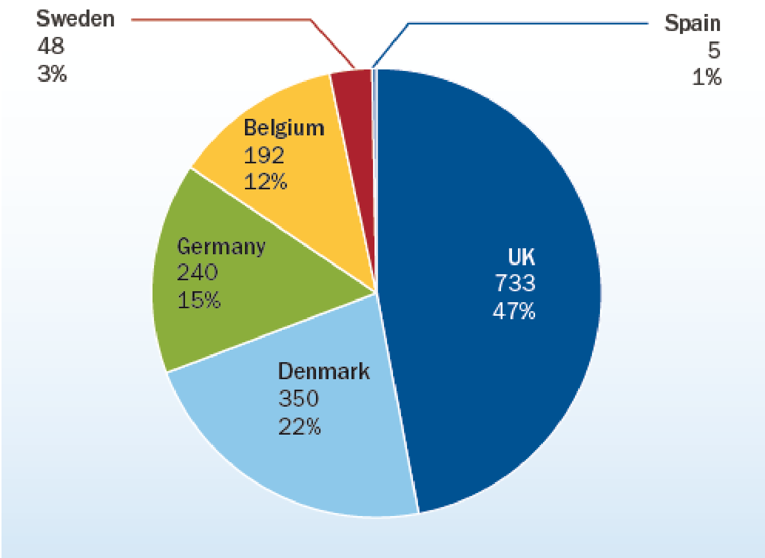


Figure 176 Share of annual offshore wind capacity installations per country during 2013 (MW) – EWEA 2014

A total of 2,080 wind turbines are now installed and connected to the electricity grid in 69 offshore wind farms in 11 countries across Europe (Figure 177). The UK has the largest amount of installed offshore wind capacity in Europe followed by Denmark. Belgium is third followed by Germany, the Netherlands, Sweden, Finland, Ireland, Norway, Spain and Portugal .

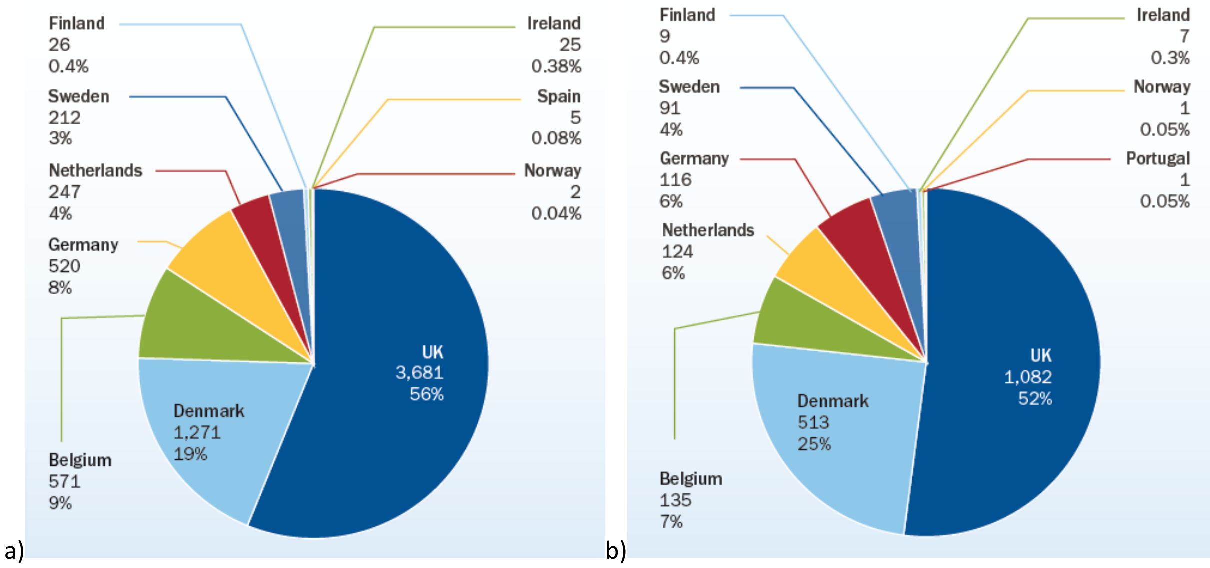


Figure 177 Cumulative share by country: installed capacity in MW (a) and installed wind turbines (b) – EWEA 2014

With regard to the market outlook for 2015, with the completion of the wind farms that are currently under construction, some 3 GW of new capacity will come online; therefore the annual installations will remain stable in 2015. Moreover, EWEA has identified 22 GW of consented offshore wind farms in Europe and future plans for offshore wind farms totalling more than 133 GW (Figure 178).

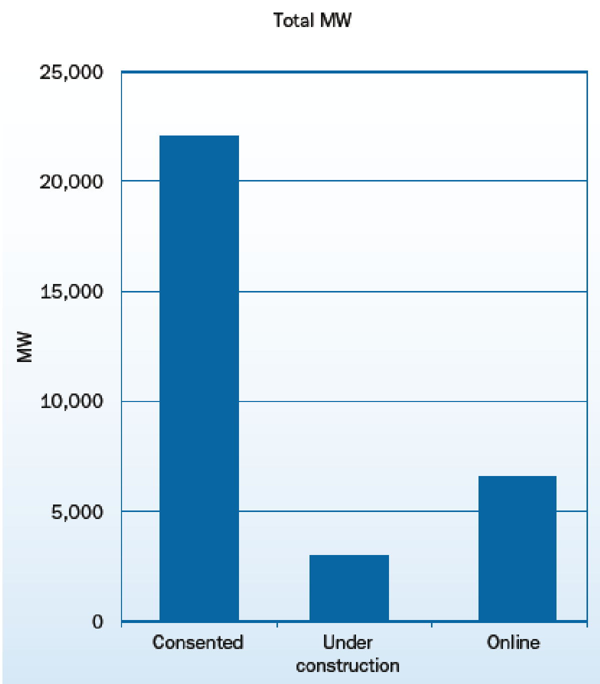


Figure 178 Offshore market: projects online, under construction and consented (MW) – EWEA 2014

In the medium term, an analysis of consented wind farms confirms that the North Sea will remain the main region for offshore deployment with significant developments foreseen in the Baltic Sea. The Mediterranean could begin exploiting its offshore potential (Figure 179).

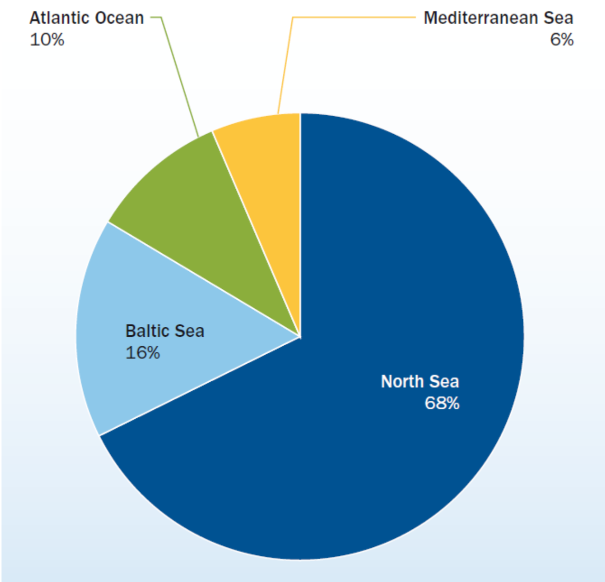
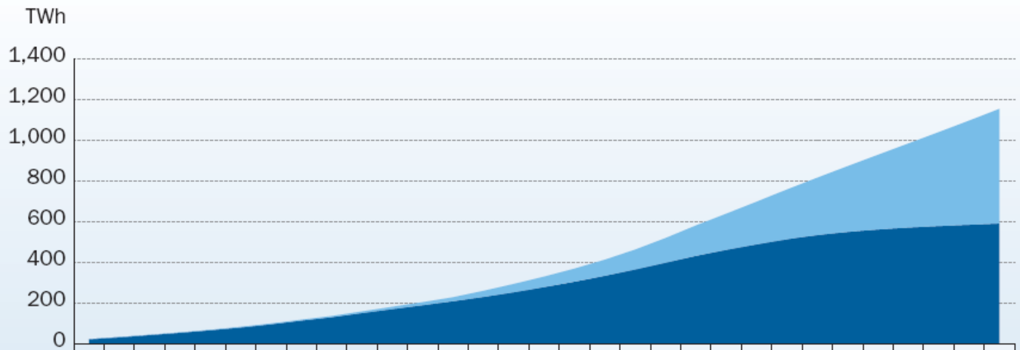


Figure 179 Share of consented offshore wind farms by sea basin– EWEA 2014

Between 2011 and 2020, EWEA expects that the total installed offshore wind capacity will grow up to 40 GW and would produce 148 TWh of electricity; approximately a quarter of Europe's wind energy would be produced offshore. In 2030, the total installed offshore wind capacity will be 150 GW that would produce 562.4 TWh of electricity, half of Europe's wind electricity produced (Figure 180).



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Offshore	0	0	1	2	2	2	3	4	5	7	11	14	19	29	40	51
Onshore	22	32	44	55	67	80	96	115	131	152	171	190	209	231	254	279
Total	23	32	44	57	69	83	100	118	136	159	182	204	229	260	294	330

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Offshore	63	78	97	120	148	177	209	244	281	322	366	412	461	511	562
Onshore	306	335	366	399	433	462	489	514	534	550	562	571	579	586	591
Total	369	413	463	519	581	639	698	757	816	873	928	983	1,040	1,096	1,154

Source: EWEA 2011

Figure 180 Electricity production from onshore and offshore wind in the EU (2000-2030)

Offshore wind energy has one **big advantage** respect to the on-shore one, namely **more constant and more powerful winds**. Offshore areas provide strong winds, with less turbulence and more predictability. However the turbines are subjected to a more intense state of stress, because of the off-shore extreme environmental conditions (waves, strong storms, brackish water and so on), which force wind turbines constructors to raise the necessary structural requirements, in particular concerning with the innovative floating turbines designed for high water depths. **The offshore wind capacity is more expensive than the onshore one**. Offshore costs depend largely on weather and wave conditions, water depth and distance to shore. The higher offshore capital costs are due to the larger structures and complex logistics for the towers installation as well as for the maintenance. The costs of offshore foundations, construction, installations and grid connection are significantly higher than for onshore. For example, offshore turbines are generally 20% more expensive, the towers and the foundations cost more than 2.5 times the price of a similar onshore project. On average, the expected investment costs for a new offshore wind farm are currently in the range of 2.0 to 2.2 million €/MW for a near-shore, shallow water facility. **The average cost of offshore wind capacity is expected to decrease of about 15% in 2015**.

The EWEA Offshore Wind Industry Working Group (OWIG) has evaluated deep offshore concept cost. It has taken account that most of the designs are still at an early stage of development and that some designs include other types of power generation such as wave energy.

To evaluate the economics of floating designs, EWEA performed a comparison with jacket foundations, whose technical characteristics allow for installation in water depths of up to 45-50m. The findings show that floating offshore wind designs are competitive in terms of levelised cost of energy (LCOE) with existing jacket foundations from around 50m water depths. For a 100 MW wind farm, equipped with 5 MW turbines and installed in water depths of 100m, the capital expenditure (CAPEX) for floating designs is similar to the CAPEX of farms using jackets or tripod foundations at 50m water depths. Similarly the cost of energy produced by the floating designs would be competitive with the fixed-bottom foundations solution.

Studies showed that the LCOE of a 500 MW wind farm in water depths of 50m would be €128/kWh, lower than the current average levelised cost of fixed-bottom foundation wind farms in shallower waters.

The **OFF-SHORE WIND ENERGY TECHNOLOGICAL AND PHYSICAL LIMITS** were then analyzed with particular focus on the Adriatic Sea environmental conditions, on the different types of foundations and support structures, on the main manufacturers and features of the offshore wind turbines, on the grid connection requirements and technologies.

Climatological studies indicate that **the three most prominent weather situations over the Adriatic are characterized by the airflow from northwest, southeast and northeast**. The Adriatic Sea is a semi-enclosed basin about 750 km long and 250 km wide with a connection to the Mediterranean Sea at the Strait of Otranto. The knowledge of the bathymetric configuration allows to split the Adriatic area in three sub-areas. The Northern Adriatic is very shallow with water depth lower than 100 m, the Middle Adriatic is characterized by a depression that reaches its maximum depth of 270m and **the South Adriatic characterized by the deepest pit of Adriatic basin of about 1200m** (Figure 181).

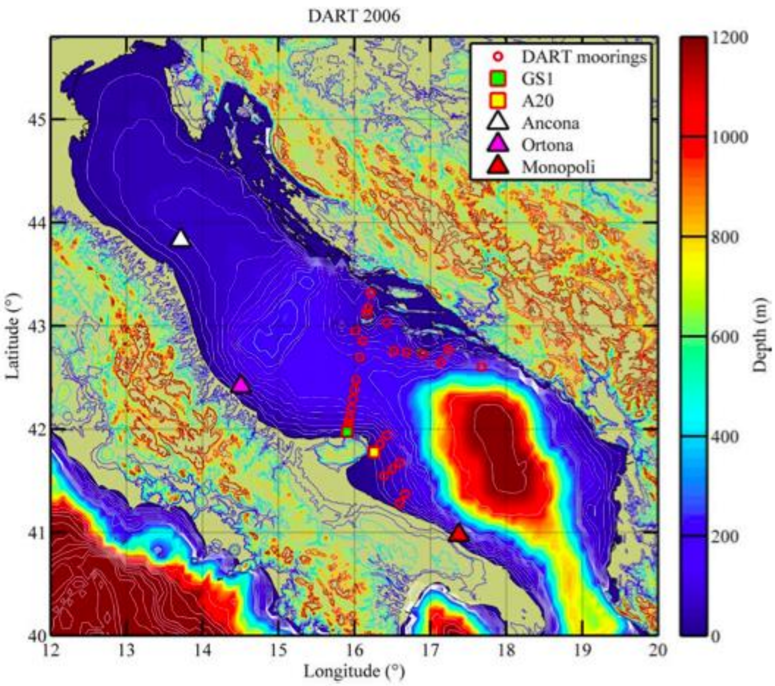


Figure 181 Bathymetry map of the Adriatic Sea

Currently, Siemens is the lead **offshore wind turbine supplier** in Europe. Vestas is the second biggest turbine supplier, followed by Senvion (REpower), BARD, WinWind and GE. Other suppliers together make up just over 1% of the market (Figure 182).

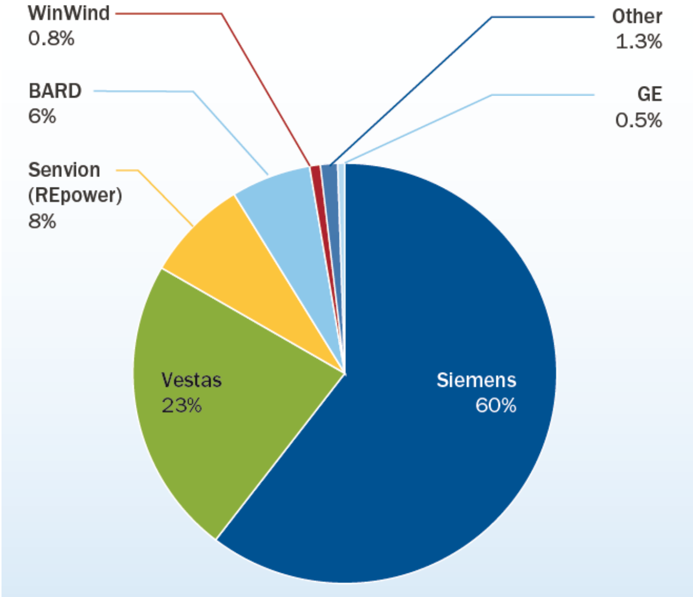


Figure 182 Wind turbine manufacturers share at the end of 2013 (MW) – EWEA 2014

The offshore commercial wind farms are constructed with bottom-fixed wind turbines. Depending on depth and soil conditions, various concepts are utilised, but most common is the monopile (Figure 183). However, at increasing depths, typically around 30 m, the monopile design reaches engineering limits. For deeper waters, the more expensive jacket foundation is a valid option. It is limited to depths of less than 50 m, not due to engineering limitations, but economic viability.

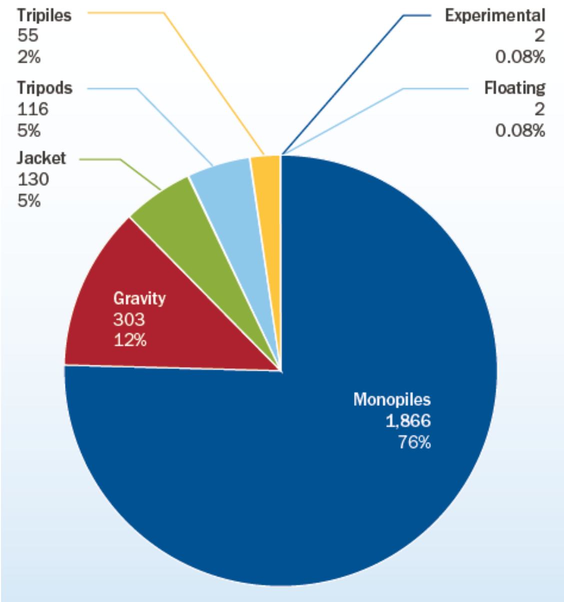


Figure 183 Share of substructure types for wind turbines – EWEA 2014

The rapid growth of offshore wind in Europe has led to the realization that it is necessary to capture the better wind resources existing further from shore in deeper waters and with larger turbines. It is also necessary for industry to cut the cost of delivered wind power below current levels. Reaching both of these goals will make the net cost of wind energy competitive with landbased wind power.

The current fixed-bottom jacket structures increase in cost with and complexity with increased water depth. At about 65 meters of water depth, the floating foundations become cost competitive with fixed-bottom structures.

Currently, Spars, Semi-submersible and Tension Leg are the three primary categories used in the offshore wind farms, adapted from the offshore oil and gas industry (Figure 184).

Numerous floating foundation design concepts are emerging and being presented to the industry:

Blue H, Hywind, Sway, WindFloat, PelaStar, Winflo, IDEOL, Hexicon and others.

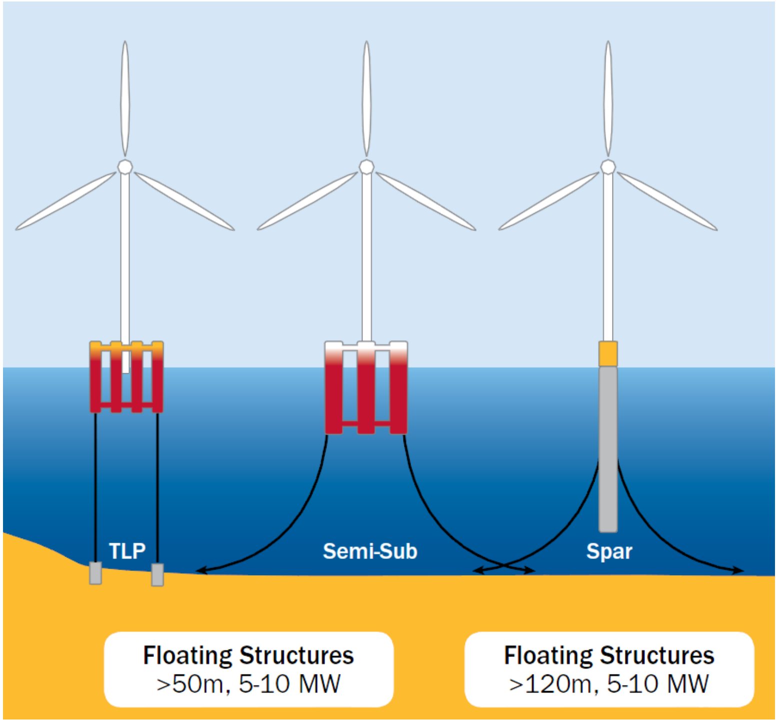


Figure 184 Floating foundation design concepts

In the HiPRwind R&D project the European Commission awarded an 11 M€ grant to a consortium of 19 partners coordinated by Fraunhofer IWES, in order to develop new structural, component, monitoring and control engineering solutions that will enable very large wind power installations in deeper waters than possible today. The project is funded within the 7th Framework Programme of the EC. It started in November 2010 and will continue through the end of 2016.

The HiPRWind project will allow to address critical issues of deep offshore wind technology such as innovative floater designs, efficient installation methods, advanced control engineering solutions and grid integration aspects of floating wind turbines. At the same time this research addresses the need for extreme reliability of components. Innovative engineering methods will be applied to selected development challenges such as rotor blade designs, structural health monitoring systems, reliable power electronics and control systems. Built-in active control features will reduce the dynamic loads on the floater in order to save weight and cost compared to existing designs.

HiPRWind will significantly reduce the risks and costs of commercializing deep water wind technology.

With regard **water depth** and **wind farm sizes**, at the end of 2013 the average water depth of online wind farms was 16 m and the average distance to shore 29 km. Looking at projects under construction, consented or planned, average water depths and distances to shore will likely increase (Figure 185).

In 2012 the average size of offshore wind was 286 MW while in 2013 it was 482 MW, 68% more than the previous year (Figure 186).

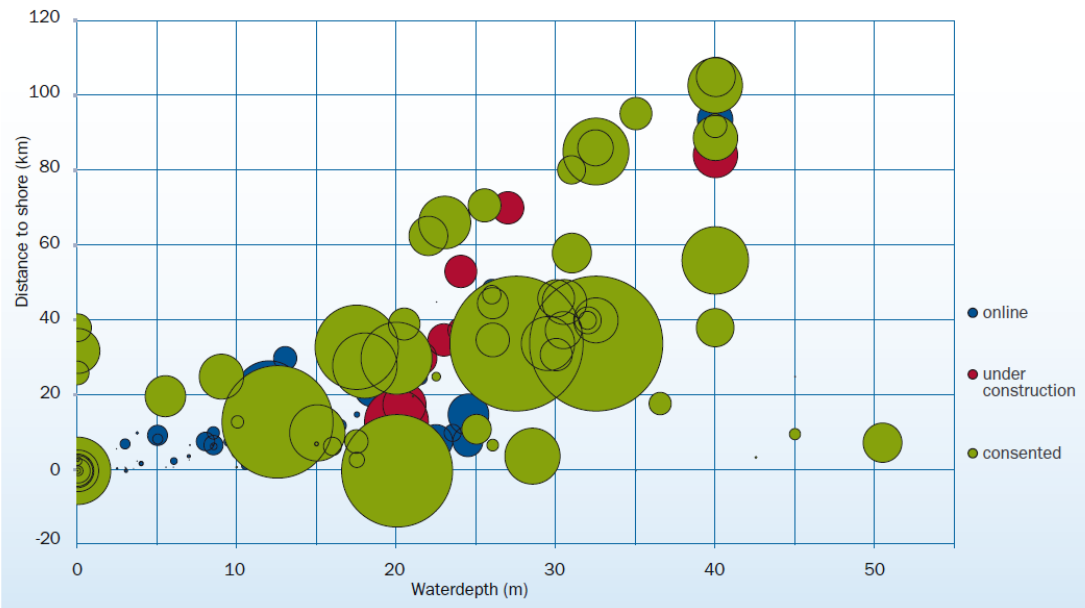


Figure 185 Average water depth and distance to shore of online, under construction and consented wind farms – EWEA 2014

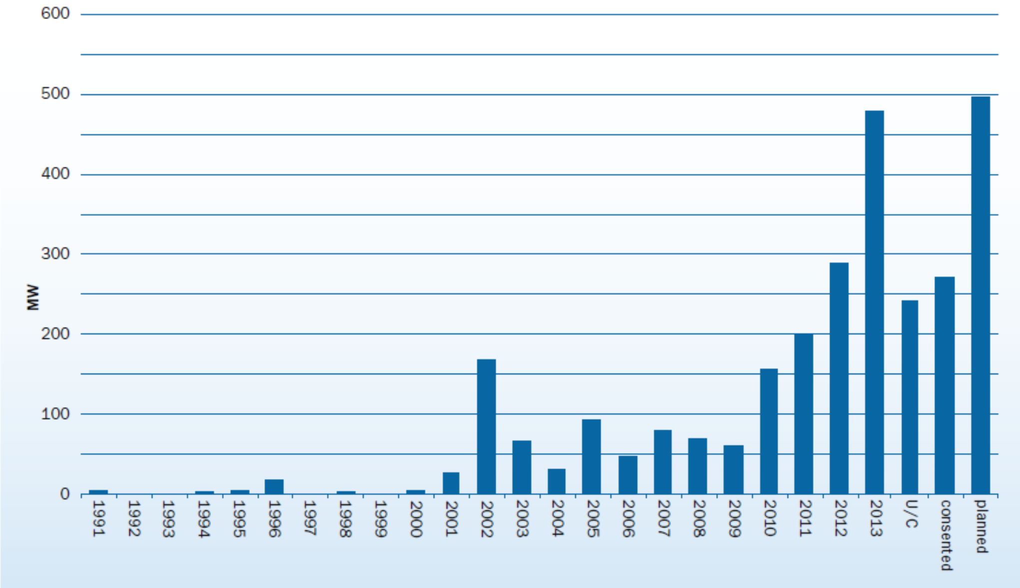


Figure 186 Average size of offshore wind farm projects – EWEA 2014

During 2013 the **average capacity** of new wind turbines installed was 3.9 MW, the same as in the previous year. Furthermore, at the end of 2013 Alstom installed the 6-MW Haliade™ 150 offshore wind turbine in the waters near Ostend Harbour at the Belwind Wind Farm in Belgium (Figure 187). This is the largest offshore wind turbine ever installed in sea waters. Thanks to its 150-metre rotor (with blades stretching 73.50 metre), the turbine is more efficient since its yield is 15% better than existing offshore turbines.

Figure 187 Alstom's Haliade 150: 6MW wind offshore turbine at Belwind site, Belgium

The growth of the offshore wind farms size, along with their distance to shore, has given to the design of the **electric transmission system** a crucial importance in terms of offshore economical feasibility. Longer transmission lines lead to higher investment costs as well as higher energy losses.

The drivers for the offshore grid favour the HVDC-VSC (High Voltage Direct Current, Voltage Source Converter) system as it is suitable for long distances with minimal losses; moreover its compactness minimizes the environmental impact and the construction costs. Furthermore, the system is modular and the technology is able to provide flexible and dynamic voltage support to AC and it can be used to support the system recovery in case of failure (Figure 188). In this way the <u>HVDC VSC technology seems to offer the solution for most of the offshore grid's technical challenges</u>.

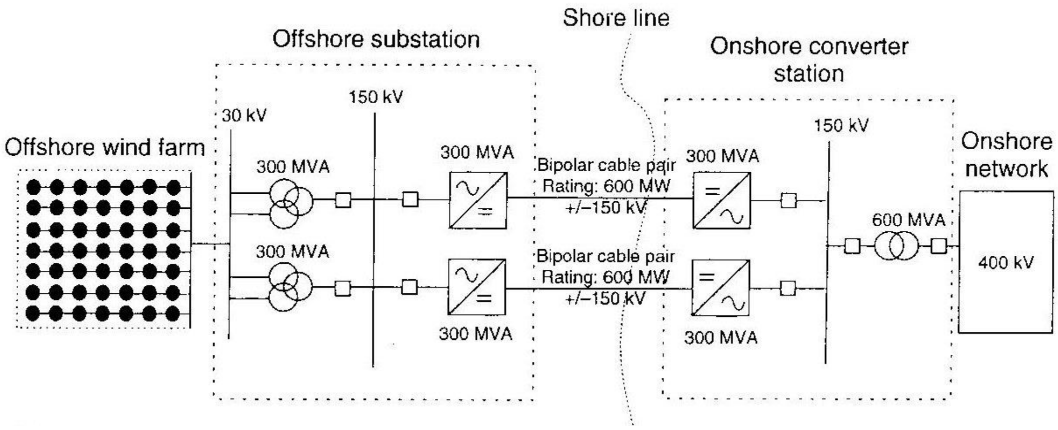


Figure 188 Basic scheme of the VSC-HVDC connection between an offshore wind farm and the main electricity grid.

To ensure a safely and efficiently operation, all customers connected to a public electricity network, must comply with the agreed technical requirements. The typical technical grid requirements are: tolerance, control of reactive power, control of active power and frequency response, protective devices, power quality and visibility of the power plant in the network.

The challenges of floating offshore wind farms grid connection from substation to shore, do not significantly differ from those for fixed foundations. The distance from the shore and the availability of networks at the point of connection remain a potential bottleneck. However, as far as cable technology is concerned, the dynamic section of the cables is an important issue. The motion induced by the turbine and the non-fixed foundation can put additional loads on the cables. In water depths of more than 100m, the array cable layout could also pose technical problems. With an array cable laid on the seabed or submerged at around 50m, a longer cable would be needed, which could lead to the cable moving. Studies of dynamic response of the cables and evaluation of cost effective solutions need to be developed.

Another challenge related to renewable electric energy is its **intermittency**. The increasing share of renewable energies calls for a technological revolution and a radical re-design of the entire production-transportation-distribution system, starting from the challenge posed by the intermittency problem that could significantly slow down this expansion. Therefore major technological innovations are needed to solve the problem of electric energy storage in a different order of magnitude and redesign the energy infrastructure to guarantee a stable and reliable electric network with high share of intermittent wind power generation.

Technologies such as pumped hydro or compressed air energy storage are suitable for large-scale energy storage needs but limited to specific sites where reservoirs are available. On the other end the traditional technologies such as batteries, flywheels, capacitors etc. capture, store and discharge electricity at a single location, but offer a very limited storage capacity (Figure 189).

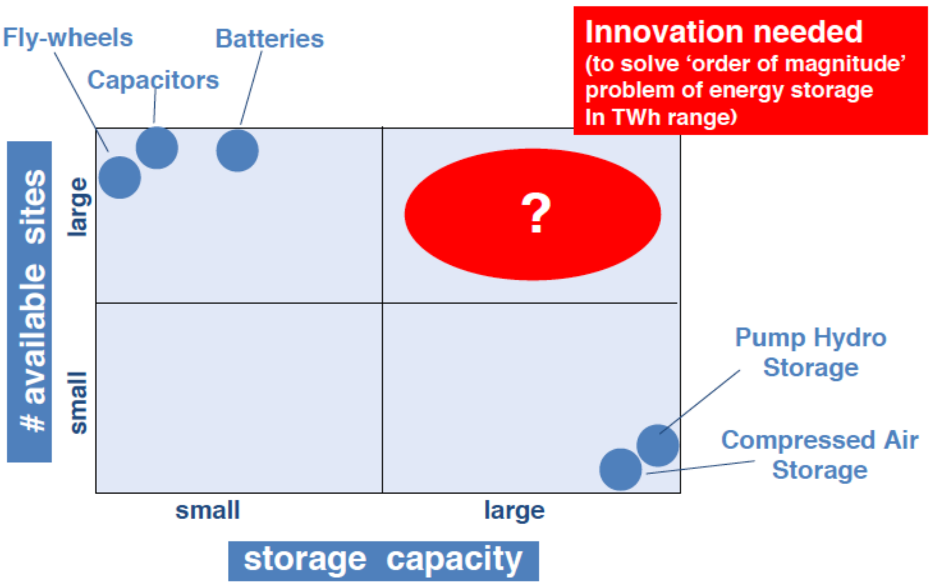


Figure 189 Electric energy storage: technology assessment

Interesting solutions to mitigating the intermittency of renewable electric energy can be offered by the "Power to Gas" technologies (P2G) in association with the highly developed infrastructure of the natural gas industry. In fact P2G technology produces a chemical energy carrier as hydrogen or SNG (Synthetic Natural Gas) that offers the highest energy storage density that can be injected in the natural gas grid (Figure 190).

A first industrial application of the technology based on electrolysis was recently inaugurated in Falkenhagen in eastern Germany in 2013 (Figure 191). E.ON in partnership with Swissgas AG built a power-to-gas (P2G) unit that uses wind power to run electrolysis equipment that transforms water into hydrogen that is injected into the regional gas transmission system. The unit has a capacity of two megawatts and can produce 360 cubic meters of hydrogen per hour.

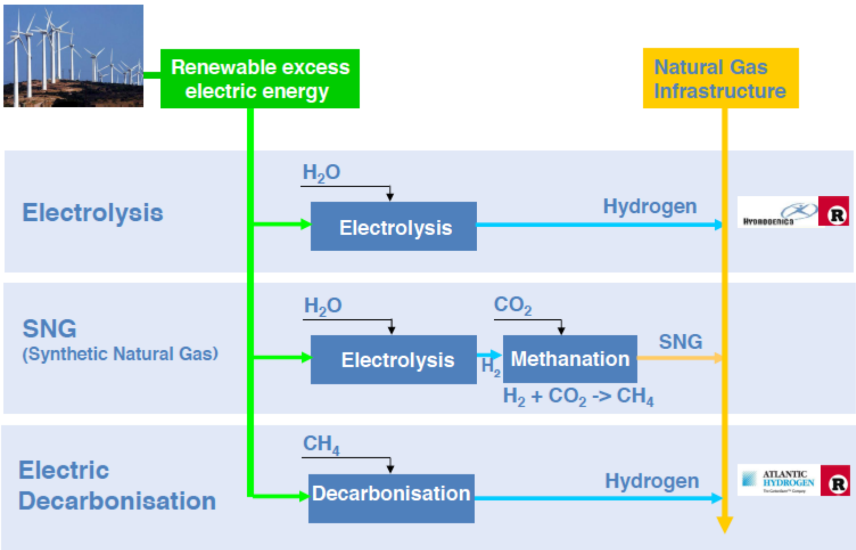


Figure 190 Power to gas: developing technologies

Figure 191 E.On Power-to-gas unit inaugurated in Falkenhagen (Germany)

Another solution to solve the problem of storing energy is to realize a wind energy platform combined with a desalination plant to supply the fresh water (Figure 192). This solution could be attractive for islands and nations with water shortage.

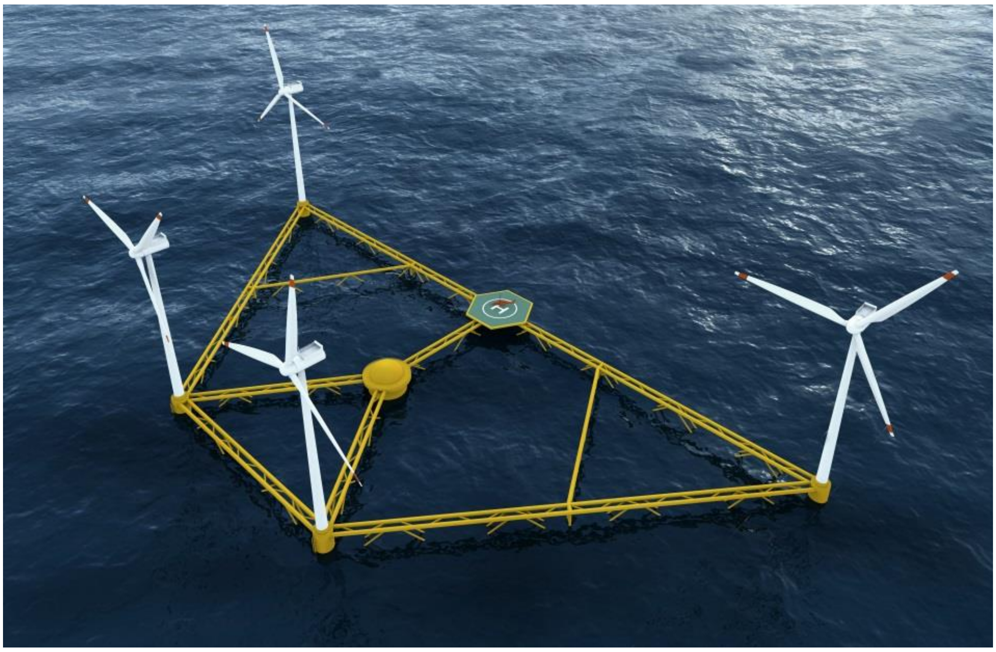


Figure 192 Hexicon platforms concept

Several **LCAs studies** have been carried out to evaluate the environmental impact of wind energy. In an offshore context, the most important contribution is due to the construction phase, accounting for about 85 per cent of the emissions and hence of the impact (Figure 193). Important items, in the environmental impacts of the construction phase of an offshore wind farm, are the nacelle and the foundations followed by the tower. The rotor blades are not found to play an important role.

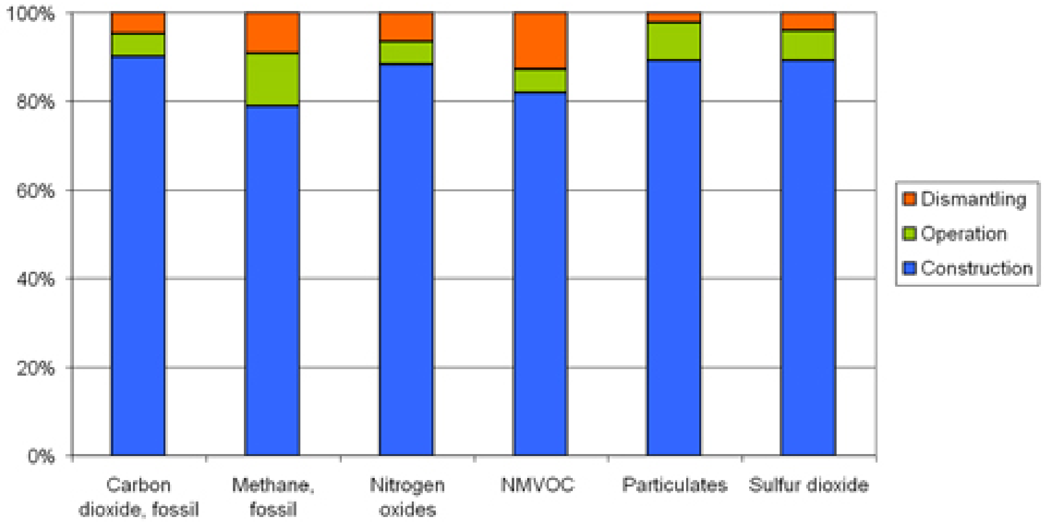


Figure 193 Contribution of the Different Life Cycle Phases of an Offshore Wind Farm to the Relevant Emissions (elaboration using ECLIPSE results)

The **TECHNOLOGIES AND MATERIALS** used to realize off-shore wind turbines components were analyzed. In particular, the materials characteristics and manufacturing processes used to date to realize the blades, the towers, the nacelle cover, the spinner and cables have been investigated.

The wind industry is a major user of <u>composites</u>, mainly for the blade manufacturing. Approximately 6.5% of an offshore wind farm is made of composites and most of the composite materials can be found in the nacelle and in the rotor blades.

To date, most turbine blades have been made in a single piece and lengthwise to avoid the technical challenges of making robust joints without significant increases in weight.

The primary technology drivers for material use for blade manufacturing are: cost, fatigue resistance, weight, ultimate tensile strength, stiffness and consistency.

The most commonly used reinforcing material in wind turbine blades are the glass fibre. Carbon fibre prepregs are also used. The resins used in the blade manufacturing are the epoxy resin and the polyester resin. Additional materials used within the composite structure of the blade include sandwich cores, surface finish coatings and adhesives (Figure 194).

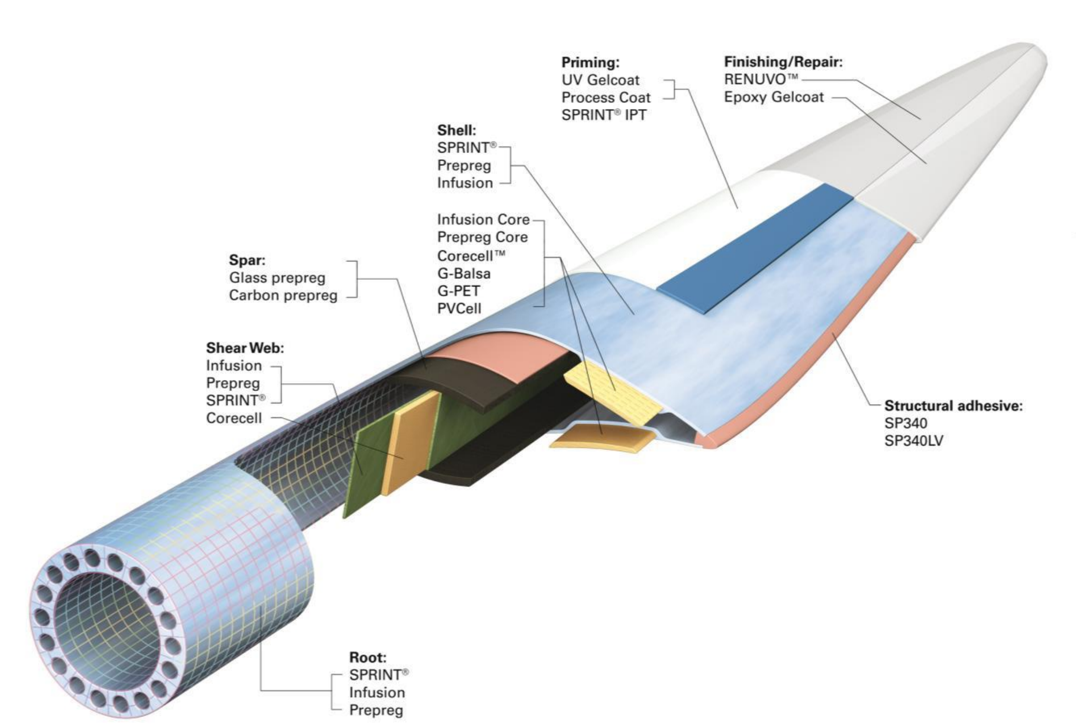


Figure 194 Composite materials in a turbine blade

Prepreg moulding or resin infusion methods, depending on the manufacturer, are used for blades manufacturing.

The nacelle cover and spinner are usually manufactured in a number of sections by using glass fibres. Resin infusion moulding and resin transfer moulding are commonly used for these components.

The rapidly expanding renewable wind energy market will inevitably have a requirement for the next generation of wind towers that will be up to, and beyond, 100m tall. Both concrete and steel are used for towers manufacturing.

Concrete towers are made using precast technique or in situ concreting techniques, such as slipforming. Precast manufacturing process minimises dimensional tolerances and guarantees a high degree of fitting accuracy during erection. Various sizes and configurations of segments can be used to take into account the lifting capacity available during construction and the transportation logistics.

In-situ concreting techniques offer the ultimate balance between maximizing construction capabilities and minimising costs. In-situ construction can overcome the problems related to the limited site access where delivery of large structural elements is difficult.

A steel tower consists of sections, typically two to four, which meet flange to flange and are bolted together. Each section is fabricated out of several individually-rolled cylindrical pieces, called shells, which are first held together by manual tack welding, then welded with submerged arc welding using a welding robot. Each section is completed by two flanges, which are mounted at the end of the shells by submerged arc welding.

The steel plates used in the fabrication of wind turbine towers vary in thickness from 12 to 75 millimetres depending on the specific design. S355 structural steel is widely used for wind turbine towers because of its high strength and low alloy content.

Concrete is easily and cost effectively adapted to large diameter foundations to produce stiffer towers. On the contrary, steel tower with larger diameters and higher wall thicknesses, required for deeper water and larger turbines, become relatively more expensive to manufacture. Moreover, concrete has high material damping properties and longer life with very little maintenance than steel and, particularly when pre-stressed, provides high levels of fatigue resistance.

Electric energy generated by offshore wind facilities requires one or more **submarine cables** to transmit the power to the onshore utility grid that services the end-users. Since the wind turbines power is generated as alternating current (AC) and the on-shore transmission grid is AC, the most straightforward technical approach is to use an AC cable system connection. The most cost effective AC technology for this type of interconnection is a solid dielectric cable, usually with cross-linked polyethylene (XLPE) insulation (Figure 195). This is the cable system technology used for all offshore wind farms already built due to the easiness of the interconnection, installation and maintenance, the operational reliability and the cost effectiveness.

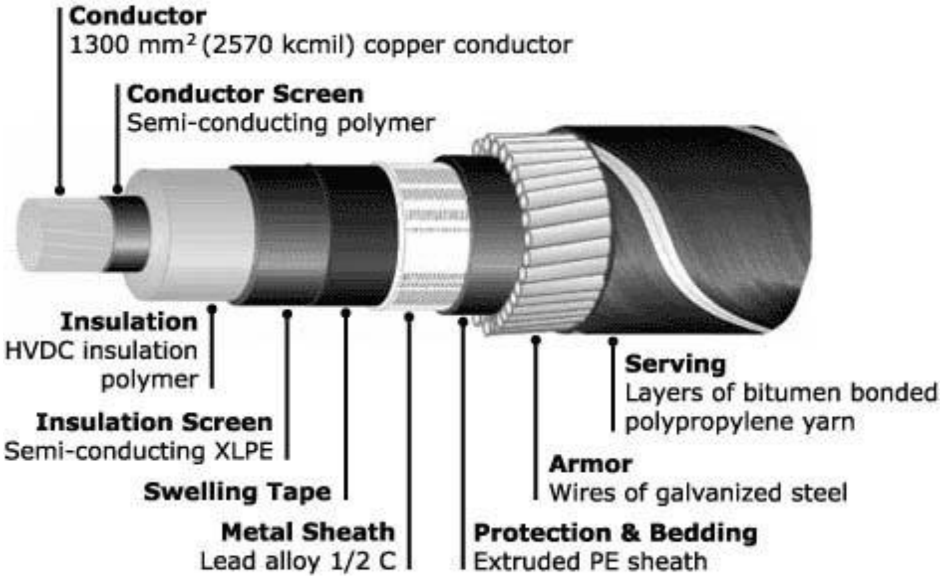


Figure 195 Anatomy of a single-core XLPE cable

With wind farms moving further offshore cables producers are seeking increasingly higher transmission capacity, which means producing larger and longer cables.
Another challenge is that cables are becoming increasingly important in risk management. One of the key differences between offshore and onshore wind farms, at the concept and design phase, is the need to consider cable failure when designing the electrical architecture. Indeed, if a submarine cable fails in service the consequences for the operability and profitability of the wind farm could be dire; especially if there are delays in securing a suitable repair vessel or if weather conditions are severe, likely during the winter months. As a consequence, it is essential that the electrical cable systems of wind farms have high reliability.
Another challenge is transport for larger and longer cables.

The **STATE OF THE ART FROM A TECHNOLOGICAL, INDUSTRIAL AND INFRASTRUCTURAL POINT OF VIEW** were investigated: the techniques adopted for the meteorological, geological and marine data measurement, the wind turbine transport and installation procedures, the submarine cabling requirements along with the installation procedures and the laying operation. Finally, the concept of reliability and the different steps to perform a reliability analysis were illustrated.
In order to proceed with the detailed planning and design of a wind off-shore farm it is necessary to acquire some fundamental elements, starting from the **meteorological and**

marine data, the **configuration of the ground** (seabed) on which the installation will take place along with the depth, the **stratigraphic composition** of the terrain, the seismic characteristic of the area, the intensity of the traffic of crafts and so on. These information will be part of the basis for the design and the reference to define the procedures and the means of transportation and installation as well as the adoption of possible protections of the structure against any scouring phenomenon on the foundation.

Meteorologists collect wind data for weather forecasts and aviation. This information is often used for a preliminary assessment of the general wind conditions in an area but they are not reliable enough for wind energy planning. In most cases the use of these data underestimates the true wind energy potential of the chosen area.

In consideration of the heavy investments associated to the wind industry, it is therefore important to make accurate measurements. To measure wind speed different types of anemometers are available: cup anemometer, hot wire anemometers, laser Doppler anemometers, and sonic anemometers. Cup anemometers tend to be more used even though they are more sensitive to extreme weather conditions (Figure 196). A part from the type of anemometer being used, what it is more important in the wind energy industry is the quality of the instrument.

Figure 196 Campbell Scientific - three cup anemometer and wind vane to measure wind speed and direction

The anemometer should be installed on the top of a mast having the same height of the hub of the wind turbine to be used. The mast preferably should be made by a thin cylindrical pole in order to minimise the turbulence caused by the airflows coming from the mast itself.

If it is placed on the side of the mast it is essential to place it in the prevailing wind direction in order to reduce the error. The data on both wind speeds and wind directions from the anemometers are registered on a data logger, and regularly transmitted or collected.

The information collected relevant to the distributions of wind speeds, and their directions are drawn on the so-called wind rose. In the sectors of the wind rose, three sets of data are represented: frequency, mean wind speed, and mean cube of wind speed. The use of the wind rose is extremely convenient for siting wind turbines since it indicates where the largest share of the wind energy comes from. National and international authorities have developed wind maps to assist the Countries and Regions in defining the most suitable areas to be allocated for wind parks. The maps can be profitably used by wind project investors to identify the possible best wind fields. The maps, however, are not sufficient for actually locating a wind turbine.

Besides the definition of the wind conditions, the design of the support structure of the offshore wind turbine requires also a careful **assessment of the external conditions at the intended site** in order to guarantee its structural integrity. This assessment therefore represents a very important preliminary activity and will consist of a site survey of the seabed soil conditions (Figure 197) along with assessment of the marine conditions including the occurrence of extreme conditions of waves, currents and tides.

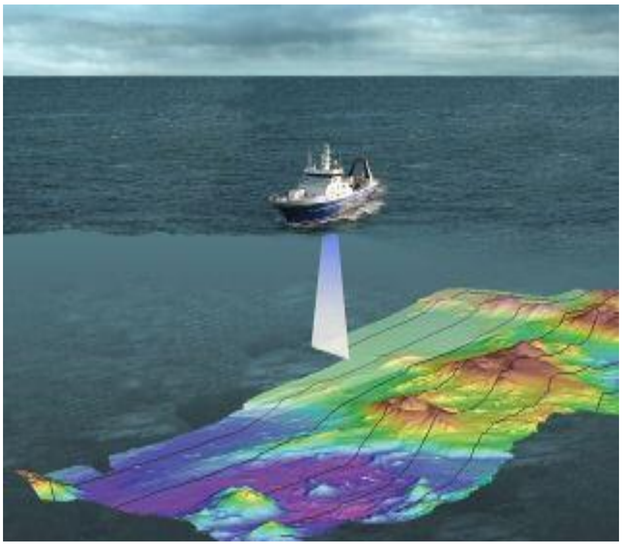


Figure 197 Seabed bathymetric analysis

The first phase of on-site investigation, commonly referred to the geophysical survey, employs remote sensing technology, often multi-beam sonar and/or high-resolution seismic reflection. This phase, known as hydro-graphic surveying, generally provides a detailed bathymetric map of the sea bottom as well as the general soil characteristics. Advanced design acitivies usually requires direct sampling of bottom soils, typically at each foundation location. This phase of investigation involves vibracore sampling up to 10 m depth or conventional borings to much greater depths.

A geophysical survey along the cable route is also required. It can be carried out using an AUV (Autonomous Underwater Vehicle) equipped with a Multi beam Echo-sounder, a Side Scan Sonar and Sub-Bottom Profiler systems.

Wave and current data are collected by instrumented buoys and Acoustic Doppler Current Profilers (ADCPs). Additional information acquired from specialized radar and satellite data, as well as regional and historic surface data sources, can further characterize the offshore environment.

The logistics for offshore wind farm installation are more complex than those for onshore projects. Unfavourable weather and sea conditions are a leading cause of construction delays, higher installation cost and risks.

Ports for wind farm installation must be able to accommodate deep draft vessels and to support large equipment offloading. In addition, they must have an adequate laydown area for turbine components (Figure 198). Typically, the available port laydown space should be roughly three-quarters to one acre per turbine. Ideally, if adequate space is available at the installation port, the hub and blade assemblies can be done onshore, minimizing the number of offshore crane operations per turbine installed. This makes the construction schedule less sensitive to weather delays. A nearby port is also essential to accommodate the O&M activity during the operational phase of the project.

Figure 198 Port of Mostyn Construction Base for Burbo Bank Offshore Wind Farm (UK)

Generally the vessels and the procedures used in the offshore wind parks operations are borrowed from the offshore oil industry. The ideal installation vessel for offshore wind farm should be a mix design between a jack up and a crane vessel. These giant jack-up vessels, on purpose-built for this expanding industry, help to overcome the difficulties of working at sea. On average, to install a wind turbine foundation it takes from 24 -36 hours up to three days, if drilling is required.

The Maintenance Vessels used for wind farms, that are closer to shore, consists of fast catamaran and monohull boats that sail in good weather conditions. The distance and location of several wind farms make the service from a port difficult, expensive, risky and time wasting. Recently it has been introduced a new concept of offshore wind farm maintenance vessels. A Maintenance Vessel will be located at the centre of the wind farm and will act as a dedicated mother ship able to offer simultaneous maintenance to several wind turbines per day. By remaining on site the transit time and the energy used for maintenance will be reduced and the good weather windows will be maximised. That means savings in costs, reduction of downtime and increased turbine availability.

Requirements of submarine cables shall comply with the laws and the regulations in force in the country where the cables will be installed and shall be designed and constructed taking into account the environmental conditions, the operational requirements and the safety aspects.

As for the environmental conditions of the installation site, the factors that may affect the life and integrity of cables materials are: temperature, polluting or corrosive substances, conditions of the sea bed, depth of installation and currents speed.

The cables shall be suitable for continuous operation (100% load factor) with short and infrequent over-currents. Moreover, all cables shall be tested during all manufacturing phases.

Before installation it is necessary to verify the bathymetric charts and the information on the seabed conditions along the cables route in order to detect the presence of any rocks or metallic objects that may damage the cable or prevent its good laying on the seabed.

The personnel to be employed shall be highly specialised and the laying vessel shall be a self-propelled vessel able to advance at slow speed in order to adjust it to the cable unwinding speed. The laying operations shall start only with favourable meteo-marine conditions forecasts for the whole period of laying. Unwinding the cable on the vessel shall be carried out with extreme care avoiding excessive stresses, keeping a bending and pulling angle within the limits imposed in the specification. The cables shall be buried at a minimum depth of 1 m below the seabed level paying attention not to damage cables. During the execution of the work several tests shall be carried out during the different phases of the operations in order to check the continuity and the good insulation of the cable. At the end of the work, it is advisable to carry out a final survey to record the cable installation that will be included in the final technical documentation.

Reliability theory is a tool for analysing and improving the availability of the system. The reliability can be measured in many ways depending on the particular situation. The *mean time to failure*, MTTF, is defined as the mean time between initial operation and the first occurrence of a failure or malfunction. When a failure has occurred the item is repaired and put back into operation; it is, then, considered as fully working. The *mean down time*, MDT, is defined as the average time that the system is not working when a component is being repaired, and is basically the time it takes to repair a failure. The *mean time between failures*, MTBF, takes into account the mean time to failure and the mean down time.

Maintenance is required for almost all types of machinery and applies also to the wind power system. In this report an explanation of three different methods for maintenance has been presented (Figure 199): corrective maintenance and two types of preventive maintenance (scheduled maintenance and condition based maintenance). Corrective maintenance is carried out after a failure and is intended to repair the system. Preventive maintenance is carried out at predetermined intervals or according to prescribed criteria and is intended to reduce the probability of a failure.

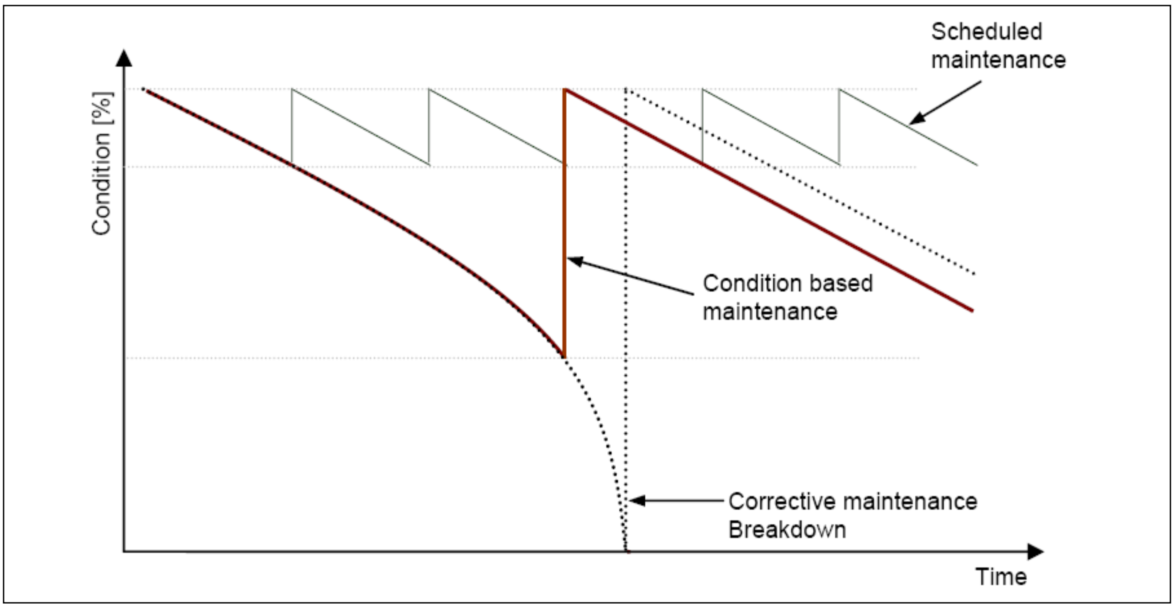


Figure 199 Condition based maintenance compared to scheduled and corrective maintenance

An ideal maintenance strategy meets the requirements of machine availability and operational safety, at minimum cost. Consequently the challenge in planning the maintenance is to decide on when to perform preventive maintenance.

Modern wind turbines achieve a quite high availability of about 95% to 99%. Nevertheless, quite a number of faults cause unscheduled down times up to ten per year, resulting in high maintenance efforts, production losses and costs. Therefore, the knowledge of failures related to certain wind turbine type is an important basis for improvement of wind turbines reliability and the development of appropriate condition monitoring maintenance systems.

The failure causes can be divided in three groups, according to frequency and severity of failures. The frequent failures, affecting electric and electronic components, which can often not be detected in advance, are more likely to be prevented through design optimization. The severity failures are dominated by unexpected wear out and are therefore more or less predictable by sophisticated condition monitoring systems. Finally, failures causes, which are often stated as unknown due to insufficient documentation, make an appropriated prevention more difficult.

With wind farms moving towards large offshore wind turbine, a very critical issue is the **structural integrity** of the rotor blades, tower and floater or the foundation respectively, and their remote maintenance. Especially the rotor blades which will have a length of 90 m and more are very critical; as a consequence, the probability of structural failure is much higher than with smaller blades. Additional to that, the environmental conditions on the sea are very harsh, that means the loads onto blades and tower are much higher. On the other hand, the accessibility of an offshore wind turbine is restricted due to sea and weather conditions and the availability of supply vessels.

Therefore, integrated structural health and condition monitoring is a prerequisite of complex remote maintenance strategies for structural parts of a wind energy converter. Structural Health Monitoring (SHM), condition-dependent and predictive maintenance combined with long-term planning of repair measures is the key to ensuring the economic viability of very large offshore turbines. Additional to the health monitoring the measurement of the dynamic behaviour of floating wind turbines is of great importance for research purposes.

The intension of SHM is not only to indicate an upcoming damage, but additionally to deliver information about the position of damage and its extent. To monitor local effects in the whole blade a sensor network is necessary covering the whole structure.

SHM is a monitoring system with 3 different measuring techniques consisting of a combination of acoustic emission, acousto-ultrasonics and the vibro-mechanic method of operational modal analysis (OMA). While the local monitoring is based on guided elastic waves, the global measurement is working with the measurement of accelerations (Figure 200).

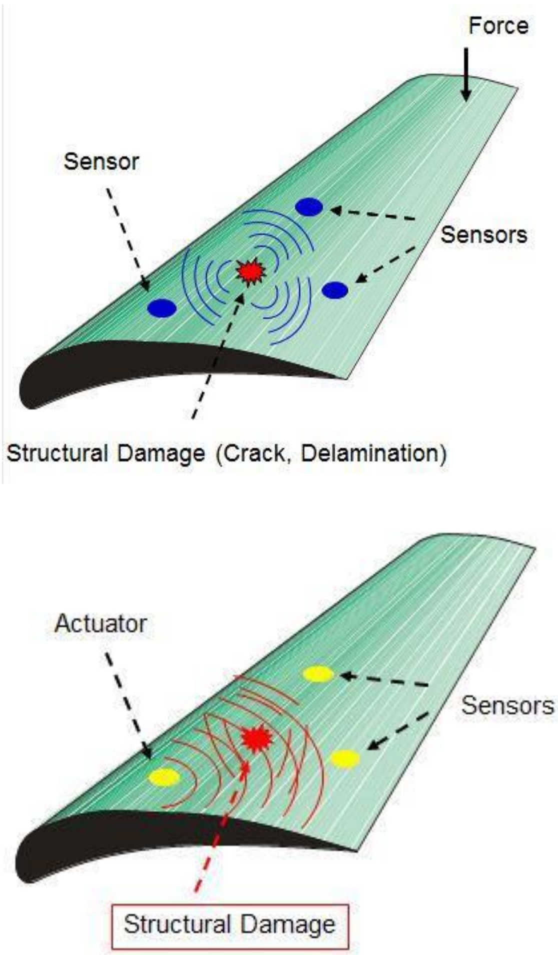


Figure 200 Functional principle of acoustic emission (left) and acoustic ultrasonics (right)

Finally, the **DISUSED OFF-SHORE PLATFORMS** requirements to house the weather station are investigated. The meteorological towers, designed for the offshore installation, are typically self-supporting lattice steel towers. On the lattice there are at least 3 levels of sensors supported by horizontal steel arms. These towers can be placed on a rather limited area within approximately 50 m^2 at the base and possible tower height can be from 60 to 100 meters. In appendix B are reported the disused offshore platforms of the Adriatic Sea and their characteristics, as general data, dimensions and sites information.

Taking into account that the offshore wind energy resource will never become a limiting factor, the challenge will be to improve the technical aspects of the EU offshore wind industry. Some of the main challenges are:

- *wind measurements and characteristics*: to acquire more detailed knowledge of the wind characteristics through the development of advanced measurement techniques and systems in order to improve wind turbine designs;
- *next generation wind turbines:* to develop the next generation offshore wind turbines, including exploring concepts of very large scale turbines in the 10-20 MW range. Wind turbine design and size must be optimised for use on floating support structures.
- *design and manufacturing:* to improve the knowledge of the actual loads applied to the components of the wind turbine; to investigate and to identify the physical characteristics of new materials, including recycling possibilities; to further develop design and verification methods for structural strength and reliability of components, such as drive trains, blades and the tower; modelling tools and numerical codes that simulate the whole structure's behaviour should be developed and validated to allow for an improved design.
- *installation and operation:* to develop standard and replicable installation processes, improving the knowledge of the physical environment to reduce development risks and uncertainty; optimise O&M strategies in order to increase availability and system reliability.
- *research and testing:* more research must be done on mooring and anchoring systems with the industry benefiting from the experience of the oil and gas sector. Furthermore, research is required into wake and turbulence effects and how they impact the load and motions of floating platforms. This can be achieved by deploying floating demonstration farms of around four or five units, not exclusively single unit prototypes. More test sites (small scale and large scale) should be developed to ensure the reliability and cost competitiveness of the deep offshore designs.

References.

[1.] http://www.ifb.uni-stuttgart.de/~doerner/ewindenergie.html;

[2.] http://www.umass.edu/windenergy/about.history.heronemus.php;

[3.] M. Bilgili, A. Yasar and E. Simsek, "Offshore wind power development in Europe and its comparison with onshore counterpart" , Renewable and Sustainable Energy Reviews 15 (2011) 905-915;

[4.] http://www.lorc.dk/Knowledge/Offshore-renewables-map/Offshore-wind-farms (It contains a list of offshore wind farms with their characteristics);

[5.] EWEA, "Pure Power – Wind energy target for 2020 and 2030", 2011;

[6.] EWEA, "The European offshore wind industry – Key 2011 trends and statistics", January 2012;

[7.] B. Snyder, M. J. Kaiser, "Ecological and economic cost-benefit analysis of offshore wind energy", Renewable Energy 34 (2009) 1567-1578;

[8.] Department of Trade and Industry, DTI. Study of the costs of offshore wind generation. A report to the Renewables Advisory Board (RAB) & DTI. URN Number 07/779; 2007b.

[9.] http://www.offshorewindenergy.org/;

[10.] EWEA, "Ocean of Opportunity", 2009;

[11.] European Wind Energy Association, (2009), "Wind Energy – The Facts". Earthscan;

[12.] www.vestas.com – Vestas V80 2 MW Technical specifications;

[13.] Ned Haluzan, "Offshore wind power – Advantages and disadvantages", February 2011;

[14.] Christina M. Jarvis, "An evaluation of the wildlife impacts of offshore wind development relative to fossil fuel power production", 2005;

[15.] http://www.greenworldinvestor.com/2011/04/18/offshore-wind-energy-vs-onshore-wind-power-advantages-and-disadvantages/;

[16.] D. Heimann. A model-based wind climatology of the eastern Adriatic coast. Meteorologische Zeitschrift, Vol. 10, No. 1, 5-16, (2001);

[17.] M. Zavatarelli and N. Pinardi. The Adriatic Sea modelling system: a nested approach. Annales Geophysicae 21: 345–364, (2003);

[18.] Z. Pasarić et al. / Journal of Marine Systems 78 (2009) S90–S100;

[19.] J.D. Dykes, D.W. Wang, J.W. Book, "An evaluation of a high-resolution operational wave forecasting system in the Adriatic Sea, Journal of Marine Systems 78 (2009) S25S S271;

[20.] W. E. de Wries et al.: 'Assessment of bottom-mounted support structure types', Project UpWind (2007);

[21.] http://www.lorc.dk/Knowledge/Wind/Support-structures

[22.] EWEA, "Wind Energy - The Facts - Part I: Technology", 2009;

[23.] AWS Truewind, LLC, "Offshore Wind Technology Overview", 2009;

[24.] IEC (2005) 'Wind Turbines – Part 1: Design requirements' International Standard 61400-1, Third Edition, International Electrotechnical Commission;

[25.] IEC (2006) 'Wind Turbines – Part 2: Design requirements for small wind turbines' International Standard 61400-2, Second Edition, International Electrotechnical Commission;

[26.] Ackermann, T., Wind power in power systems, John Wiley and Sons, 2005 - 691 pp.

[27.] GTZ Expert Workshop 2010: Grid and System Integration of Wind Energy, 22/23.11.2010, Berlin/Germany;

[28.] EWEA, "Powering Europe: wind energy and the electricity grid", 2010;

[29.] ELECTRICITY STORAGE - POST office of Houses of Parliament April 2008 Number 306 www.parliament.uk/parliamentary_offices/post/pubs2008.cfm;

[30.] The need for electricity storage. www.megawattsf.com] . [Challenges of Electricity Storage Technologies - A Report from the APS Panel on Public Affairs Committee on Energy and Environment May2007 - www.aps.org/policy/reports/popa reports/upload/Energy_2007_Report_ElectricityStorageReport.pdf;

[31.] EWEA, "Wind Energy - The Facts - Part V: Environmental Issues", 2009;

[32.] Offshore wind: Opportunities for the composites industry, BVG Associates (2011);

[33.] James C. Watson and Juan C. Serrano, "Composite Materials for Wind Blades", 2010;

[34.] Princeton Energy Resources International, LLC – "Wind Turbine – Materials and Manufacturing Fact Sheet", 2001;

[35.] "Concrete Towers for Onshore and Offshore Wind Farms", The Concrete Centre, 2007;

[36.] A.N. Singh, “Concrete construction for wind energy towers”, The Indian Concrete Journal, 2007;

[37.] Marcus Klose, " Design of Concrete Structures for Offshore Wind Turbines”, Germanischer Lloyd WindEnergie GmbH;

[38.] K. Zipp: ‘Welding challenges in the fabrication of offshore wind towers’, Windpower Engineering (2010);

[39.] Wright, S.D., Rogers, A.L., Manwell, J.F., Ellis, A., “Transmission Options for Offshore Wind Farms in the United States,” AWEA, 2002;

[40.] Gilbertson, Oswald I., Electrical cables for Power and Signal Transmission, Wiley, 2000.

[41.] Prof.F.G.Cesari, Ing.F.Taraborrelli “IMPIANTI EOLICI OFFSHORE” Università di Bologna - DIENCA-LIN;

[42.] WIND TUTRBINE MANUAL Danish Wind Industry Association (DWIA) - http://www.windpower.org/en/;

[43.] Prof. M. Natarajan, Er. K. Mohan and Prof. T. Balasubramanian “Waves and Tides” Centre of Advanced Study in Marine Biology - Annamalai University;

[44.] C. Accadia, G. Arena, A. Barbano et alt. “Il sistema idro-meteo-mare e le reti di monitoraggi dell’APAT” - www.arpalombardia.it/.../25_5meteoeclima_03_ACCADIArel.pdf;

[45.] W. Musial, S. Butterfield, B. Ram “Energy from Offshore Wind” OTC Houston 1-4 May 2006;

[46.] The infrastructural requirements necessary to facilitate the development of the offshore wind industry to identify electrical network impacts of offshore power plants. Report on the Second ORECCA Workshop 64/71 - 65 /71 – 66/71 – 67/71 – 68/71;

[47.] G.J.W. van Bussel, A.R. Henderson et al. “State of the Art and Technology Trends for Offshore Wind Energy: Operation and Maintenance Issues” Concerted Action on Offshore Wind Energy in Europe [CA-OWEE] www.offshorewindenergy.org;

[48.] S. Dambone Sessa “Studio multiconduttore matriciale di cavi sottomarini in corrente alternata” tesi specialistica 2010 università di Padova cap.I Sistemi di Trasmissione in cavo;

[49.] System Reliability Theory, M. Rausand, A. Hoyland, Hoboken: John Wiley & Sons 2004, ISBN 0-471-47133-X

[50.] Maintenance terminology, Svensk Standard SS-EN 13306, 2001

[51.] Handbook of condition Monitoring, A. Davies, London: Chapman & Hall 1998, ISBN 0-412-61320-4

[52.] Reliability Theory with application preventive maintenance, I. Gertsbakh, Berlin: Springer-Verlag 2000, ISBN 3450-67275-3

[53.] Handbook of Condition Monitoring, B. K. N. Rao (ed.), Oxford: Elsevier Science Ltd 1996, ISBN 1-85617-234-1

[54.] Stefan Faulstich (Fraunhofer IWES), "Component reliability ranking with respect to WT concept and external environmental conditions", Project UpWind

[55.] Eecen, P., J., Branlard, E., The OWEZ Meteorological Mast – Analysis of mast-top displacements, NordzeeWind - ECN-E-08-067;

[56.] D.M. 14 Gennaio 2008: Norme Tecniche delle Costruzioni (NTC 2008);

[57.] CNR-DT 207/2008: Istruzioni per la valutazione delle azioni e degli effetti del vento sulle costruzioni;

[58.] www.calzavara.it

[59.] "Renewable energy and natural gas – solutions for mitigating intermitteny" Joachim Wilhelm Technology Development Director of Rosetti Marino SpA. REM Ravenna 29 Feb 2012.

[60.] "The smart gas grid:state of the art and perspectives". E. Crisostomi, A. Franco, M. Raugi Dep. of Energy – University of Pisa; G. Giunta Optimization & Trading dept - eni SpA-

[61.] Hydrogenics – Power to gas solutions - www.hydrogenics.it

[62.] www.eon.com press release 28 August 2013

[63.] http://www.alstom.com/press-centre/2013/11/alstom-installing-worlds-largest-offshore-wind-turbine-/

[64.] http://www.gamesacorp.com/en/communication/news/ending-of-the-azimut-project-that-will-enable-the-development-of-a-15-mw-offshore-wind-turbine-in-2020.html?idCategoria=60

[65.] http://www.principlepowerinc.com/products/windfloat.html

[66.] http://www.sway.no/publish_files/57051.pdf

[67.] PelaStar Technology, 29 February 2012

[68.] http://glosten.com/sectors/offshore-wind-front-end-engineering-design-study/

[69.] http://en.dcnsgroup.com/news/winflo-lenergie-du-large-en-escale-a-tokyo/

[70.] http://www.ideol-offshore.com/

[71.] HANSA International Maritime Journal – 151. Jahrgang – 2014 – Nr. 12

[72.] http://www.hexicon.eu/offshore-platforms.html

[73.] http://www.hiprwind.eu/

[74.] EWEA, “Wind in power: 2013 european statistics”, February 2014;

[75.] EWEA, “Deep Water - The next step for offshore wind energy”, July 2013;

[76.] EWEA, “The European offshore wind industry - key trends and statistics 2013”, January 2014;

[77.] Anders Myhr, Catho Bjerkseter, Anders Ågotnes, Tor A. Nygaard, “Levelised cost of energy for offshore floating wind turbines in a life cycle perspective”, Renewable Energy 66 (2014) 714-728

[78.] H. Friedmann, C. Ebert, P. Kraemer and B. Frankenstein, “SHM of Floating Offshore Wind Turbines - Challenges and First Solutions”, 6th European Workshop on Structural Health Monitoring - Fr.1.B.2

[79.] Garrad Hassan (2012) ‘Cost of energy of floating wind’.

APPENDIX A - Table of offshore wind farms

Project Name	Country	Capacity (MW)	Operating Year	Status	No. Turbines	Turbine Size (MW)	Turbine Model	Water Depth (m)	Distance from Shore (km)	Foundation Type
Vindeby	Denmark	5	1991	Commissioned	11	0.45	Siemens 450	3 to 5	1.5	Gravity
Lely	Netherlands	2	1994	Commissioned	4	0.5	NEG Micon	5 to 10	1	Monopile
Tuno Knob	Denmark	5	1995	Commissioned	10	0.5	Vestas 500 kW	3 to 5	6	Gravity
Dronten/Irene Vorrink	Netherlands	16.8	1996	Commissioned	28	0.6	Nordtank	5	0	Monopile
Bockstigen	Sweden	2.75	1997	Commissioned	5	0.55	NEG Micon 550 kW	6	3	Monopile
Blyth	United Kingdom	4	2000	Commissioned	2	2	Vestas V66	9	1	Monopile
Middelgrunden	Denmark	40	2001	Commissioned	20	2	Bonus 2 MW	5 to 10	2 to 3	Gravity
Yttre Stengrund	Sweden	10	2001	Commissioned	5	2	NEG Micon 2 MW	8	5	Monopile
Horns Rev	Denmark	160	2002	Commissioned	80	2	Vestas V80	6 to 14	14 to 17	Monopile
Samsoe	Denmark	23	2002	Commissioned	10	2.3	Siemens 2.3	11 to 18	3	Monopile
Utgrunden	Sweden	11.4	2002	Commissioned	8	1.425	Enron 1.425	7 to 10	8 to 12	Monopile
Frederikshavn	Denmark	10.6	2003	Commissioned	2 1 1	3 2.3 2.5	Vestas V90 Bonus 2.3 Nordex N90	1	1	Monopile, Bucket
North Hoyle	United Kingdom	60	2003	Commissioned	30	2	Vestas V80	5 to 12	8	Monopile
Sky 2000	Germany	150	2003	Commissioned	50		Repower MM82	20	17	Tripod
Emden Nearshore	Germany	4.5	2004	Commissioned	1	4.5	Enercon	3	0	N/A
Rodsand I/Nysted	Denmark	165.6	2004	Commissioned	72	2.3	Siemens 2.3	6 to 10	6 to 10	Gravity
Ronland	Denmark	17.2	2004	Commissioned	8	2	Vestas V80	1	0	Monopile
Scroby Sands	United Kingdom	60	2004	Commissioned	30	2	Vestas V80	2 to 10	3	Monopile
Setana	Japan	1.32	2004	Commissioned	2	0.66	Vestas V47	13	1	N/A
Arklow Bank	Ireland	25	2005	Commissioned	7	3.6	GE 3.6	2 to 5	10	Monopile
Kentish Flats	United Kingdom	83	2005	Commissioned	30	3	Vestas V90	5	9	Monopile
Barrow	United Kingdom	90	2006	Commissioned	30	3	Vestas V90	15	7	Monopile
Beatrice (Moray Firth)	United Kingdom	10	2006	Commissioned	2	5	REpower 5M	43	25	Jacket
Rostock	Germany	2.5	2006	Commissioned	1	2.5	Nordex 2.5 MW	2	1	N/A
Blue H Puglia (Pilot)	Italy	0.08	2007	Commissioned	1	0.08	WES18 mk1	108	20	Floating
Bohai Bay	China	1.5	2007	Commissioned	1	1.5	Goldwind	N/A	70	Jacket
Burbo Bank	United Kingdom	90	2007	Commissioned	25	3.6	Siemens 3.6	10	5.2	Monopile
Egmond aan Zee (Nordzee Wind)	Netherlands	108	2007	Commissioned	36	3	Vestas V90	17 to 23	8 to 12	Monopile
Inner Dowsing	United Kingdom	97.2	2007	Commissioned	27	3.6	Siemens 3.6	10	5	Monopile
Lynn	United Kingdom	97.2	2007	Commissioned	27	3.6	Siemens 3.6	10	5	Monopile
Hooksiel (Demonstration)	Germany	5	2008	Commissioned	1	5	BARD 5 MW	2 to 8	1	Tripile
Kemi Ajos Phase I	Finland	15	2008	Commissioned	5	3	WindWinD 3 MW	N/A	0 to 1 km	Artificial Island
Lillgrund Oresund	Sweden	110	2008	Commissioned	48	2.3	Siemens 2.3	2.5 to 9	10	Gravity
Princess Amalia (Q7-WP)	Netherlands	120	2008	Commissioned	60	2	Vestas V80	19 to 24	> 23	Monopile
Alpha Ventus/Borkum West	Germany	60	2009	Financed/Under Construction	6 6	5 5	Multibrid M5000 REpower 5M	30	45	Tripod Jacket
Gasslingegrund (Lake Vanern)	Sweden	30	2009	Financed/Under Construction	10	3	(DynaWind AB)	4 to 10	4	N/A
Gunfleet Sands Phase I	United Kingdom	108	2009	Financed/Under Construction	30	3.6	Siemens 3.6	2 to 15	7	Monopile
Gunfleet Sands Phase II	United Kingdom	64	2009	Financed/Under Construction	18	3.6	Siemens 3.6	2 to 15	7	Monopile
Horns Rev Expansion	Denmark	210	2009	Financed/Under Construction	91	2.3	Siemens 2.3	9 to 17	30	Monopile
Hywind/Karmoy (Floating Pilot)	Norway	2.3	2009	Partially Commissioned	1	2.3	Siemens 2.3	120 to 700	10 km initially	Floating
Kemi Ajos Phase II	Finland	15	2009	Financed/Under Construction	5	3	WindWinD 3 MW	N/A	0 to 1 km	N/A
Rhyl Flats/Constable Bank	United Kingdom	90	2009	Partially Commissioned	25	3.6	Siemens 3.6	8	8	Monopile
Robin Rigg (Solway Firth)	United Kingdom	180	2009	Financed/Under Construction	60	3	Vestas V90	>5	10	Monopile
Sprogo	Denmark	21	2009	Financed/Under Construction	7	3	Vestas V90	6 to 15	1	Gravity
Thornton Bank	Belgium	30	2009	Commissioned	6	5	REpower 5M	25	30	Gravity
Avedore/Hvidovre	Denmark	15	2010	Financed/Under Construction	3	5	N/A	N/A	20 to 100	N/A
Baltic I	Germany	48.3	2010	Financed/Under Construction	21	2.3	Siements 2.3	18	16	N/A
Bard Offshore I	Germany	400	2010	Financed/Under Construction	80	5	BARD 5 MW	39 to 41	100	Tripile
Greater Gabbard Phase I	United Kingdom	150	2010	Financed/Under Construction	140	3.6	Siemens 3.6	24 to 34	25	Monopile
Nordergrunde	Germany	90	2010	Financed/Under Construction	18	5	REpower 5M	4 to 20	30	Monopile or Jacket
Rodsand II	Denmark	207	2010	Financed/Under Construction	90	2.3	Siemens 2.3	5 to 12	6 to 10	Gravity
Sea Bridge	China	102	2010	Financed/Under Construction	34	3	Sinovel 3 MW	8 to 10	8 to 14	N/A
Walney Island Phase I	United Kingdom	183.6	2010	Financed/Under Construction	51	3.6	Siemens 3.6	20	15	N/A
Belwind	Belgium	165	2011	Financed/Under Construction	55	3	Vestas V90	20 to 35	46	Gravity
Borkum West II	Germany	400	2011	Financed/Under Construction	80	5	Multibrid M5000	22 to 33	45	Tripod
Ormonde	United Kingdom	150	2011	Financed/Under Construction	30	5	REpower 5M	17 to 22	10	Jacket
Thanet	United Kingdom	300	2011	Financed/Under Construction	100	3	Vestas V90	20 to 25	7 to 9	Monopile
Borkum Riffgat	Germany	264	2012	Financed/Under Construction	44	5	N/A	16 to 24	15	N/A
London Array Phase I	United Kingdom	630	2012	Financed/Under Construction	175	3.6	Siemens 3.6	23	>20	Monopile
Sheringham Shoal	United Kingdom	316.8	2012	Financed/Under Construction	88	3.6	Siemens 3.6	16 to 22	17 to 23	Monopile
Walney Island Phase II	United Kingdom	183.6	2012	Financed/Under Construction	51	3.6	Siemens 3.6	20	15	N/A

The table lists the commissioned and/or financed/under construction offshore wind farms, including their main characteristics.

APPENDIX B – Adriatic sea disused off-shore platforms

General Data	
Platform Name	**ANEMONE 2**
Installation date	1973
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C8.ME
Concession expiry date	n/a
Decommission date	2000
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	16
Seabed depth (m)	22
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°41’31’’,43
Latitude	44°13’27’’,44
12 miles	on12
Coastline distance (km)	20

General Data	
Platform Name	CERVIA 25
Installation date	1986
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	CERVIA MARE
Concession expiry date	n/a
Decommission date	2000
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	16
Seabed depth (m)	23
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°38’03’’,70
Latitude	44°17’28’’,80
12 miles	on12
Coastline distance (km)	21

General Data	
Platform Name	CERVIA MARE 3
Installation date	1966
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	CERVIA MARE
Concession expiry date	n/a
Decommission date	1985
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	18
Seabed depth (m)	22
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°39’46’’,26
Latitude	44°16’28’’,69
12 miles	on12
Coastline distance (km)	18

General Data	
Platform Name	CESENATICO MARE 1
Installation date	1961
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	CESENATICO MARE
Concession expiry date	n/a
Decommission date	1991
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	18
Seabed depth (m)	10
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°28’26’’,96
Latitude	44°14’05’’,40
12 miles	on12
Coastline distance (km)	6

General Data	
Platform Name	CESENATICO MARE 3
Installation date	1965
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C28.EA
Concession expiry date	n/a
Decommission date	1991
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	18
Seabed depth (m)	10
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°27'31'',18
Latitude	44°14'56'',70
12 miles	on12
Coastline distance (km)	6

General Data	
Platform Name	CESENATICO MARE 4
Installation date	1965
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C28.EA
Concession expiry date	n/a
Decommission date	1991
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	18
Seabed depth (m)	9
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°26’13’’,38
Latitude	44°15’25’’,70
12 miles	on12
Coastline distance (km)	5

General Data	
Platform Name	FLAVIA 1
Installation date	1985
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	B.C16.AG
Concession expiry date	n/a
Decommission date	n/a
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	13
Seabed depth (m)	10
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZB
I.I.M. Sheet	922/M
Longitude	13°53’16’’,08
Latitude	43°02’41’’,71
12 miles	on12
Coastline distance (km)	6

General Data	
Platform Name	FPSO-FIRENZE
Installation date	1998
Platform Tipology	n/a
Mineral	OLIO
Company	ENI
Concession where the platform is installed	F.C 2.AG
Concession expiry date	n/a
Decommission date	2006
Number of linked gas wells	2
Connection to the power plant	n/a
UNMIG Section	NA
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	25
Seabed depth (m)	850
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZF
I.I.M. Sheet	920/M
Longitude	18°19’34’’,59
Latitude	40°55’25’’,07
12 miles	off12
Coastline distance (km)	50

General Data	
Platform Name	FULVIA 1
Installation date	1985
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	B.C16.AG
Concession expiry date	n/a
Decommission date	n/a
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	18
Seabed depth (m)	12
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZB
I.I.M. Sheet	922/M
Longitude	13°53’50’’,26
Latitude	43°01’20’’,58
12 miles	on12
Coastline distance (km)	6

General Data	
Platform Name	GELA 2
Installation date	1968
Platform Tipology	n/a
Mineral	OLIO
Company	ENI
Concession where the platform is installed	C.C 1.AG
Concession expiry date	n/a
Decommission date	n/a
Number of linked gas wells	2
Connection to the power plant	n/a
UNMIG Section	SI
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	13
Seabed depth (m)	10
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZC
I.I.M. Sheet	917/M
Longitude	14°15’25’’,92
Latitude	37°02’20’’,72
12 miles	on12
Coastline distance (km)	2

General Data	
Platform Name	LAVINIA
Installation date	1981
Platform Tipology	Submarine Wellhead
Mineral	GAS
Company	ENI
Concession where the platform is installed	D.C 3.AG
Concession expiry date	n/a
Decommission date	2009
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	NA
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	85
Seabed depth (m)	90
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZD
I.I.M. Sheet	919/M
Longitude	17°10’41”
Latitude	39°20’51”
12 miles	on12
Coastline distance (km)	4

General Data	
Platform Name	MILA 4
Installation date	1985
Platform Tipology	n/a
Mineral	OLIO
Company	EDISON
Concession where the platform is installed	C.C 4.EO
Concession expiry date	n/a
Decommission date	2003
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	NA
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	-45
Seabed depth (m)	52
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZC
I.I.M. Sheet	917/M
Longitude	14°30’43’’,00
Latitude	36°44’28’’,00
12 miles	on12
Coastline distance (km)	7

General Data	
Platform Name	MILA 5
Installation date	1980
Platform Tipology	n/a
Mineral	OLIO
Company	EDISON
Concession where the platform is installed	C.C 4.EO
Concession expiry date	n/a
Decommission date	2003
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	NA
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	-52
Seabed depth (m)	58
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZC
I.I.M. Sheet	917/M
Longitude	14°30’11’’,00
Latitude	36°44’14’’,00
12 miles	on12
Coastline distance (km)	7

General Data	
Platform Name	MILA 6
Installation date	1985
Platform Tipology	n/a
Mineral	OLIO
Company	EDISON
Concession where the platform is installed	C.C 4.EO
Concession expiry date	n/a
Decommission date	2003
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	NA
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	-45
Seabed depth (m)	52
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZC
I.I.M. Sheet	917/M
Longitude	14°29’23’’,00
Latitude	36°44’10’’,00
12 miles	on12
Coastline distance (km)	7

General Data	
Platform Name	MORMORA 1/4
Installation date	1985
Platform Tipology	n/a
Mineral	GAS
Company	EDISON
Concession where the platform is installed	B.C 7.LF
Concession expiry date	n/a
Decommission date	2005
Number of linked gas wells	0
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	12
Seabed depth (m)	15
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZB
I.I.M. Sheet	922/M
Longitude	13°50'36'',92
Latitude	43°15'59'',91
12 miles	on12
Coastline distance (km)	7

General Data	
Platform Name	NARCISO 2
Installation date	1985
Platform Tipology	n/a
Mineral	OLIO
Company	ENI
Concession where the platform is installed	C.C8.AG
Concession expiry date	n/a
Decommission date	1997
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	NA
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	20
Seabed depth (m)	21
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZC
I.I.M. Sheet	948/M
Longitude	12°23’54’’,27
Latitude	37°53’10’’,32
12 miles	on12
Coastline distance (km)	4

General Data	
Platform Name	NILDE
Installation date	1982
Platform Tipology	n/a
Mineral	OLIO
Company	ENI
Concession where the platform is installed	C.C2.AS
Concession expiry date	n/a
Decommission date	1989
Number of linked gas wells	2
Connection to the power plant	n/a
UNMIG Section	NA
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	-
Seabed depth (m)	100
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZC
I.I.M. Sheet	948/M
Longitude	11°54’56’’,00
Latitude	37°32’33’’,00
12 miles	off12
Coastline distance (km)	57

General Data	
Platform Name	PORTO CORSINI 1
Installation date	1966
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C26.EA
Concession expiry date	n/a
Decommission date	1968
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	13
Seabed depth (m)	24
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°32’39’’,00
Latitude	44°23’58’’,00
12 miles	on12
Coastline distance (km)	15

General Data	
Platform Name	PORTO CORSINI 3
Installation date	1963
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C26.EA
Concession expiry date	n/a
Decommission date	1988
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	18
Seabed depth (m)	22
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°31’13’’,49
Latitude	44°24’12’’,76
12 miles	on12
Coastline distance (km)	13

General Data	
Platform Name	PORTO CORSINI 4
Installation date	1964
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C26.EA
Concession expiry date	n/a
Decommission date	1990
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	18
Seabed depth (m)	22
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°31’25’’,87
Latitude	44°25’08’’,75
12 miles	on12
Coastline distance (km)	14

General Data	
Platform Name	PORTO CORSINI 6
Installation date	1965
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C26.EA
Concession expiry date	n/a
Decommission date	1966
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	13
Seabed depth (m)	24
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°34'10'',20
Latitude	44°23'20'',40
12 miles	on12
Coastline distance (km)	16

General Data	
Platform Name	PORTO CORSINI 7A
Installation date	1966
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C26.EA
Concession expiry date	n/a
Decommission date	1990
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	18
Seabed depth (m)	25
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°35’03’’,94
Latitude	44°23’23’’,03
12 miles	on12
Coastline distance (km)	17

General Data	
Platform Name	PORTO CORSINI 7B
Installation date	1965
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C26.EA
Concession expiry date	n/a
Decommission date	1990
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	18
Seabed depth (m)	25
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°35’23’’,06
Latitude	44°22’59’’,01
12 miles	on12
Coastline distance (km)	17

General Data	
Platform Name	PORTO CORSINI 8
Installation date	1966
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C26.EA
Concession expiry date	n/a
Decommission date	1990
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	18
Seabed depth (m)	24
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°33'38'',54
Latitude	44°23'51'',13
12 miles	on12
Coastline distance (km)	16

General Data	
Platform Name	PORTO CORSINI 9
Installation date	1965
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C26.EA
Concession expiry date	n/a
Decommission date	1967
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	13
Seabed depth (m)	24
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°35'26'',60
Latitude	44°22'42'',20
12 miles	on12
Coastline distance (km)	18

General Data	
Platform Name	PORTO CORSINI 1 Bis
Installation date	1968
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C26.EA
Concession expiry date	n/a
Decommission date	1999
Number of linked gas wells	8
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	40
Seabed depth (m)	25
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°34’26’’,70
Latitude	44°23’14’’,60
12 miles	on12
Coastline distance (km)	21

General Data	
Platform Name	PORTO CORSINI 10
Installation date	1966
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C26.EA
Concession expiry date	n/a
Decommission date	1990
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	18
Seabed depth (m)	25
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°34’38’’,38
Latitude	44°23’18’’,70
12 miles	on12
Coastline distance (km)	17

General Data	
Platform Name	PORTO CORSINI 11
Installation date	1966
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C26.EA
Concession expiry date	n/a
Decommission date	1990
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	18
Seabed depth (m)	25
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°32’18’’,91
Latitude	44°24’36’’,32
12 miles	on12
Coastline distance (km)	15

General Data	
Platform Name	PORTO CORSINI 12
Installation date	1966
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C26.EA
Concession expiry date	n/a
Decommission date	1990
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	18
Seabed depth (m)	25
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°34’41’’,86
Latitude	44°23’08’’,16
12 miles	on12
Coastline distance (km)	17

General Data	
Platform Name	PORTO CORSINI 25
Installation date	1976
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C26.EA
Concession expiry date	n/a
Decommission date	1996
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	18
Seabed depth (m)	23
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°34’47’’,56
Latitude	44°22’44’’,71
12 miles	on12
Coastline distance (km)	17

General Data	
Platform Name	PORTO CORSINI 25 BIS
Installation date	1976
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C26.EA
Concession expiry date	n/a
Decommission date	1996
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	18
Seabed depth (m)	23
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°34'32'',86
Latitude	44°23'06'',04
12 miles	on12
Coastline distance (km)	17

General Data	
Platform Name	PORTO CORSINI 26
Installation date	1978
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C26.EA
Concession expiry date	n/a
Decommission date	2000
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	15
Seabed depth (m)	25
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°32’06’’,00
Latitude	44°24’55’’,60
12 miles	on12
Coastline distance (km)	18

General Data	
Platform Name	PORTO CORSINI 27
Installation date	1979
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C26.EA
Concession expiry date	n/a
Decommission date	2000
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	15
Seabed depth (m)	24
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°33’08’’,00
Latitude	44°23’55’’,60
12 miles	on12
Coastline distance (km)	19

General Data	
Platform Name	PORTO CORSINI 30
Installation date	1982
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C26.EA
Concession expiry date	n/a
Decommission date	2000
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	15
Seabed depth (m)	24
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°32'35'',90
Latitude	44°23'21'',30
12 miles	on12
Coastline distance (km)	19

General Data	
Platform Name	PORTO CORSINI A
Installation date	1967
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C26.EA
Concession expiry date	n/a
Decommission date	1999
Number of linked gas wells	4
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	31
Seabed depth (m)	25
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°34’22’’,80
Latitude	44°23’38’’,70
12 miles	on12
Coastline distance (km)	21

General Data	
Platform Name	PORTO CORSINI B
Installation date	1968
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C26.EA
Concession expiry date	n/a
Decommission date	1999
Number of linked gas wells	8
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	25
Seabed depth (m)	25
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°34’29’’,18
Latitude	44°23’16’’,35
12 miles	on12
Coastline distance (km)	6

General Data	
Platform Name	PORTO CORSINI B Alloggi
Installation date	1968
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C26.EA
Concession expiry date	n/a
Decommission date	1986
Number of linked gas wells	0
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	35
Seabed depth (m)	25
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°34’31’’,52
Latitude	44°23’18’’,03
12 miles	on12
Coastline distance (km)	17

General Data	
Platform Name	PORTO CORSINI W A Alloggi
Installation date	1968
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C26.EA
Concession expiry date	n/a
Decommission date	1995
Number of linked gas wells	0
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	35
Seabed depth (m)	13
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°21’37’’,91
Latitude	44°30’40’’,87
12 miles	on12
Coastline distance (km)	5

General Data	
Platform Name	PORTO CORSINI W B Alloggi
Installation date	1968
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C26.EA
Concession expiry date	n/a
Decommission date	1995
Number of linked gas wells	0
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	35
Seabed depth (m)	14
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°22’29’’,17
Latitude	44°30’32’’,01
12 miles	on12
Coastline distance (km)	6

General Data	
Platform Name	PORTO CORSINI W PROD
Installation date	1968
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C26.EA
Concession expiry date	n/a
Decommission date	1995
Number of linked gas wells	8
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	25
Seabed depth (m)	13
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°21’31’’,69
Latitude	44°30’39’’,28
12 miles	on12
Coastline distance (km)	5

General Data	
Platform Name	PORTO GARIBALDI MARE 1
Installation date	1968
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C01.AG
Concession expiry date	n/a
Decommission date	1991
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	18
Seabed depth (m)	25
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°31'34'',60
Latitude	44°29'05'',00
12 miles	on12
Coastline distance (km)	16

General Data	
Platform Name	PUNTA MARINA 2
Installation date	1965
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C27.EA
Concession expiry date	n/a
Decommission date	1992
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	18
Seabed depth (m)	9
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°20’26’’,58
Latitude	44°26’11’’,67
12 miles	on12
Coastline distance (km)	3

General Data	
Platform Name	PUNTA MARINA 3
Installation date	1966
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C27.EA
Concession expiry date	n/a
Decommission date	1991
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	18
Seabed depth (m)	9
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°21’15’’,60
Latitude	44°25’56’’,93
12 miles	on12
Coastline distance (km)	3

General Data	
Platform Name	RAVENNA MARE 4
Installation date	1960
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C27.EA
Concession expiry date	n/a
Decommission date	2000
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	10
Seabed depth (m)	10
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°23’44’’,80
Latitude	44°24’40’’,50
12 miles	on12
Coastline distance (km)	7

General Data	
Platform Name	RAVENNA MARE 5
Installation date	1962
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C 27.EA
Concession expiry date	n/a
Decommission date	1991
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	13
Seabed depth (m)	10
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°24’27’’,10
Latitude	44°24’13’’,30
12 miles	on12
Coastline distance (km)	7

General Data	
Platform Name	RAVENNA MARE 6 BIS
Installation date	1963
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C27.EA
Concession expiry date	n/a
Decommission date	1991
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	18
Seabed depth (m)	10
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°22’44’’,02
Latitude	44°24’45’’,41
12 miles	on12
Coastline distance (km)	4

General Data	
Platform Name	RAVENNA MARE 7
Installation date	1963
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C27.EA
Concession expiry date	n/a
Decommission date	2000
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	10
Seabed depth (m)	12
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°22’22’’,80
Latitude	44°24’41’’,40
12 miles	on12
Coastline distance (km)	8

General Data	
Platform Name	RAVENNA MARE A
Installation date	1968
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C27.EA
Concession expiry date	n/a
Decommission date	1995
Number of linked gas wells	10
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	20
Seabed depth (m)	10
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°23’27’’,00
Latitude	44°25’03’’,00
12 miles	on12
Coastline distance (km)	5

General Data	
Platform Name	RAVENNA MARE A Alloggi
Installation date	1967
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C27.EA
Concession expiry date	n/a
Decommission date	1995
Number of linked gas wells	0
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	35
Seabed depth (m)	10
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°23'29'',24
Latitude	44°25'04'',54
12 miles	on12
Coastline distance (km)	5

General Data	
Platform Name	RAVENNA MARE SUD 5
Installation date	1962
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C27.EA
Concession expiry date	n/a
Decommission date	1999
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	13
Seabed depth (m)	10
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°24’27’’,10
Latitude	44°24’13’’,30
12 miles	on12
Coastline distance (km)	7

General Data	
Platform Name	RAVENNA SUD 1
Installation date	1963
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C27.EA
Concession expiry date	n/a
Decommission date	1999
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	10
Seabed depth (m)	9
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°21'10'',00
Latitude	44°23'41'',60
12 miles	on12
Coastline distance (km)	3

General Data	
Platform Name	RAVENNA SUD 5
Installation date	1968
Platform Tipology	n/a
Mineral	GAS
Company	ENI
Concession where the platform is installed	A.C27.EA
Concession expiry date	n/a
Decommission date	1999
Number of linked gas wells	1
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	10
Seabed depth (m)	9
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZA
I.I.M. Sheet	924/M
Longitude	12°21’28’’,90
Latitude	44°23’25’’,50
12 miles	on12
Coastline distance (km)	3

General Data	
Platform Name	S.GIORGIO MARE 4
Installation date	1972
Platform Tipology	n/a
Mineral	GAS
Company	EDISON
Concession where the platform is installed	B.C 2.LF
Concession expiry date	n/a
Decommission date	2005
Number of linked gas wells	0
Connection to the power plant	n/a
UNMIG Section	BO
Status	decommissioned
Notes	dismessa
Dimensions	
Above Mean Sea Level (AMSL) elevation (m)	12
Seabed depth (m)	18
Above Mean Sea Level Structure Dimensions	n/a
Site	
Zone	ZB
I.I.M. Sheet	922/M
Longitude	13°55'02'',00
Latitude	43°12'36'',00
12 miles	on12
Coastline distance (km)	11