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WIND ENERGY REPORT GERMANY 2011

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Kassel, July 2012

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FOREWORD

Energy provision in Germany, the rest of Europe, and worldwide is facing its biggest ever challenge, namely switching from the current mix to carbon-free energy generation. Wind energy has been designated as the key player in the transformation to electricity generation from renewable energy sources. This will, however, only be possible if there is continuing advancement of turbine technology and effective integration into the grid and system control.

Following the Energy Concept 2010, the German government made a decision, based on the events in Fukushima in June 2011, to pull out of nuclear energy, namely to change its energy policy. As such, the expansion and integration of renewable energies have become vitally important for future electricity generation. By 2050 the aim is for wind energy to provide 50% of the energy requirement [Energy Concept 2050, BMU, BMWI, 2010-09]. Onshore and offshore wind power generation capacity is planned to grow to a total of ca. 45,000 MW by 2020 and 85,000 MW by 2050.

The Energy Concept of the German government plans considerable acceleration of the expansion of offshore wind energy generation, with a total of 25,000 MW installed capacity planned in the North Sea and Baltic Sea by 2030. In the short and medium term onshore wind energy utilization is the most economical of all the renewable energy sources and has considerable scope for expansion. Indeed, a study on the potential of onshore wind energy utilization for the Bundesverband WindEnergie e.V. has shown that developing 2% of the land in Germany for wind energy can provide ca. 65% of the gross energy requirement of Germany.

The central matters for the further development of wind energy utilization are systematic reduction of the mechanical loads on wind turbines (leading to weight and cost savings), improvement of the service life and availability, improvement of the logistics for transport and installation, greater electricity generation using very high hubs, reliable assessment of site conditions, and effective integration into the electricity supply system.

Experts at the Fraunhofer IWES are working in these areas to enable efficiently generated electricity to drive further economic growth. The Wind Energy Report Germany is published annually and replaces the former WMEP annual report. The Fraunhofer IWES has published these reports since 1991 to provide information and statistics about the development of wind energy in Germany.

A key part of the reports covers the technical progress that has been made and environmental developments. In 2009 the report was extended to also cover offshore wind energy and since then has provided a detailed overview of wind energy utilization in Germany.

The Wind Energy Report Germany 2011 describes the current status of wind energy utilization worldwide and gives a detailed account of developments in Germany up until now. Further information can be found at www.windmonitor.de.

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EXECUTIVE SUMMARY

Wind energy of **47 TWh** meant that **wind energy provided just under 8% of the total German energy requirement in 2011**. In December alone, some 8 TWh were generated by wind turbines. However, the wind conditions in 2011 were below the long-term average. During the course of the year, new wind turbines having a total nominal power of **2051 MW (onshore and offshore) were installed**. This meant that at the end of 2011 a total of about **22,200 wind turbines were installed in Germany generating 28,818 MW**. Germany currently sits in third place behind China and the USA with regards to the available wind power generation capacity.

Onshore. The trend on land towards ever larger wind turbines continues unabated. The 2 to 3 MW class dominate the market. Rotor diameters and tower heights are increasing and there is growing specialization in turbines for high and low wind locations. There is potential for further expansion of onshore wind energy, in particular in the southern German states and via repowering. According to the Renewable Energy Act (German: EEG), more than 10,000 wind turbines that were installed before 2002 are suitable for repowering.

Offshore. Following the alpha ventus pilot project, the start up of Bard 1 and Baltic 1 marked the first commercial offshore wind farms in Germany to be fully or partially operational. At the end of 2011, **Germany had about 200 MW of wind power generating capacity installed offshore**. Expansion will be further accelerated by the 2012 amendment to the Renewable Energy Act. Indeed, offshore wind power generation is growing worldwide. Great Britain currently has the most offshore wind power generating capacity (1660 MW). China has also significantly increased its offshore generating capacity.

Regarding the development of new turbine concepts for offshore use, the trend is towards direct drive wind turbines. Other innovative developments are taking place in support structures, with currently various concepts undergoing trials.

Grid expansion. Further expansion of the offshore generating capacity means ever bigger challenges for the electricity grids to manage the increased wind power and hence greater power fluctuations. As a result of **power feed-in management, about 127 GWh of wind energy output was lost in 2010 due to downpowering**, with the grid operators paying compensation of 10 million euros to wind turbine operators.

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WIND IN THE RENEWABLE ENERGY MIX

In 2011 the total gross electricty generation in Germany was 612 TWh. Some 20% of this originated from renewable energy sources. The biggest renewable player in 2011 was wind power: In total just under 47 TWh was supplied to the electricity grid in 2011 from wind energy. This represented 7.7% of the total electricity generation (2010: 6.2%). Other major renewable contributors in 2011 were biomass with 6% (5.5% in 2010), hydroelectric with 3.2% (3.4% in 2010), and photovoltaic energy with a notable 3.1% (1.9% in 2010). In 2011 waste-fueled power plants accounted for 0.8% of the total electricty generated, the same percentage as in 2010. Wind turbine operators benefited in 2011 from a very strong December.

Since 1990 the contribution of hydroelectric power to the energy mix portion has been roughly constant whilst the contributions from photovoltaics, biomass, and wind energy have significantly increased. In 2011 wind energy represented 38% of all the electricty generated from renewable sources. Back in 1990 this was just 1%, as illustrated in Figures 1 and 2.

Expansion of wind energy utilization in Germany. Figure 3 shows the wind power generation capacity in Germany over the period from 1990 to 2011. During this period, onshore wind power generation capacity increased from ca. 100 MW to just under 28,700 MW.

Following the rapid growth of wind power utilization, the expansion of onshore wind power generating capacity has slowed somewhat in recent years. For example, the growth rate up to 2003 was over 20%, but since 2007 it has been below 10%. In 2011, however, there was considerably more new onshore wind power generating capacity installed in Germany (1923 MW) than in 2010 (1420 MW). The growth rate was about 7%.

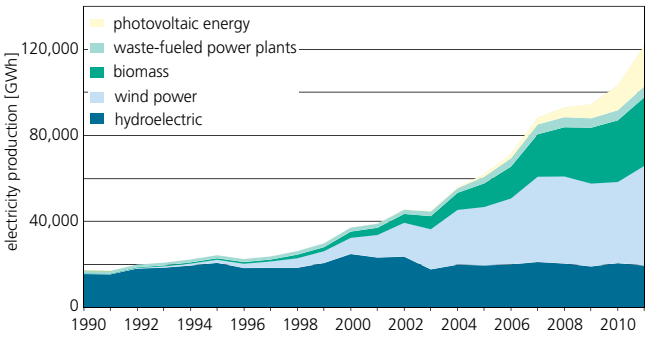


Figure 1: Electricity production from renewable energies since 1990. Data source: BMU 2012

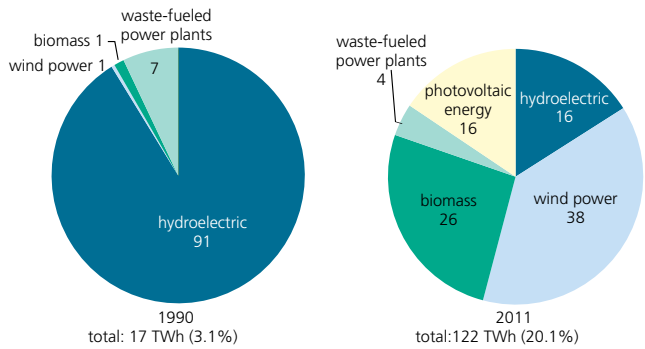


Figure 2: The renewable energy mix in 1990 and 2011. Data source: BMU 2012

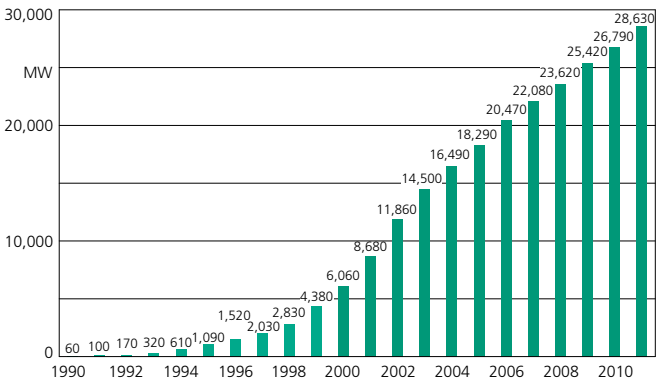


Figure 3: Growth in onshore wind power generation capacity in Germany. Data source: IWET

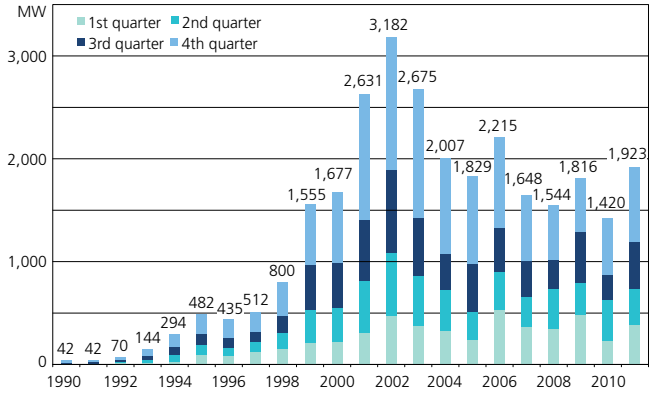


Figure 4: Wind power generating capacity installed onshore annually in Germany. Data source: IWET

WIND ENERGY UTILIZATION ONSHORE

Finding suitable locations is vital in order to expand wind energy utilization onshore. New wind turbines are increasingly being installed inland away from the shore and also in the low mountain regions. At existing locations older wind turbines are being repowered, namely replaced by fewer but more powerful WTs.

In the Special Report "Wind energy utilization onshore - wind conditions and suitable locations", Dr. Bofinger presents the results of a study commissioned by the BWE. The study appraises the land area of Germany for its suitability for wind energy utilization. The conclusion is that 8% of the total area is available for classical wind energy utilization. If forested areas and conservation areas are also included, then the available land area increases to 12.3% and 22.4% respectively. For a scenario in which solely 2% of the land was utilized for wind energy utilization, a total nominal power of 198 GW could be installed. For about 2000 hours operating at full load per year, ca. 65% of the total electricity requirement of Germany in 2010 could be generated.

Further information can be found on Page 53.

Figure 4 shows the newly installed onshore wind power generating capacity year by year. Whereas before 1990 only several tens of MWs were newly installed each year, since 1999 this has been considerably above the 1000 MW mark. In 2002 there was almost 3200 MW of new generating capacity installed, the most in a year up until now. Since 2003 a certain saturation of the German market has been observed. In 2010 the net annual growth fell to about 1400 MW and this rose again in 2011 to about 1900 MW.

Up until the mid 1990s the installation of wind turbines in Germany mainly took place in coastal regions, because here the prevailing wind conditions were best for commercial utilization. Over the course of the years more and more wind turbines have been built far inland and in the low mountain regions of Germany. The start up of alpha ventus in November 2010 marked the beginning of offshore wind power generation for Germany.

Figure 5 shows the clear north-south split in the utilization of wind energy. Lower Saxony, Brandenburg, and Saxony-Anhalt have the most wind turbines and the largest wind power generating capacity. In Schleswig-Holstein, Lower Saxony and North Rhine-Westphalia there is considerable scope for repowering, due to the many turbines that were installed here around the millennium.

Of all the states, Lower Saxony installed the most new wind turbines (WTs) in 2011, namely 178, having a total generating capacity of 426 MW. Next came Schleswig-Holstein (ca. 277 MW / 112 WTs) and Rhineland-Palatinate (ca. 257 MW / 112 WTs).

There is currently much less wind power generation capacity in the southern German states, especially in Bavaria and Baden-Württemberg. Currently Bavaria and Baden-Württemberg have respectively only 9 kW and 14 kW of installed wind power generating capacity per square kilometer of land surface. In the states in the north of Germany this value is between about 150 kW and 205 kW per square kilometer of land surface.

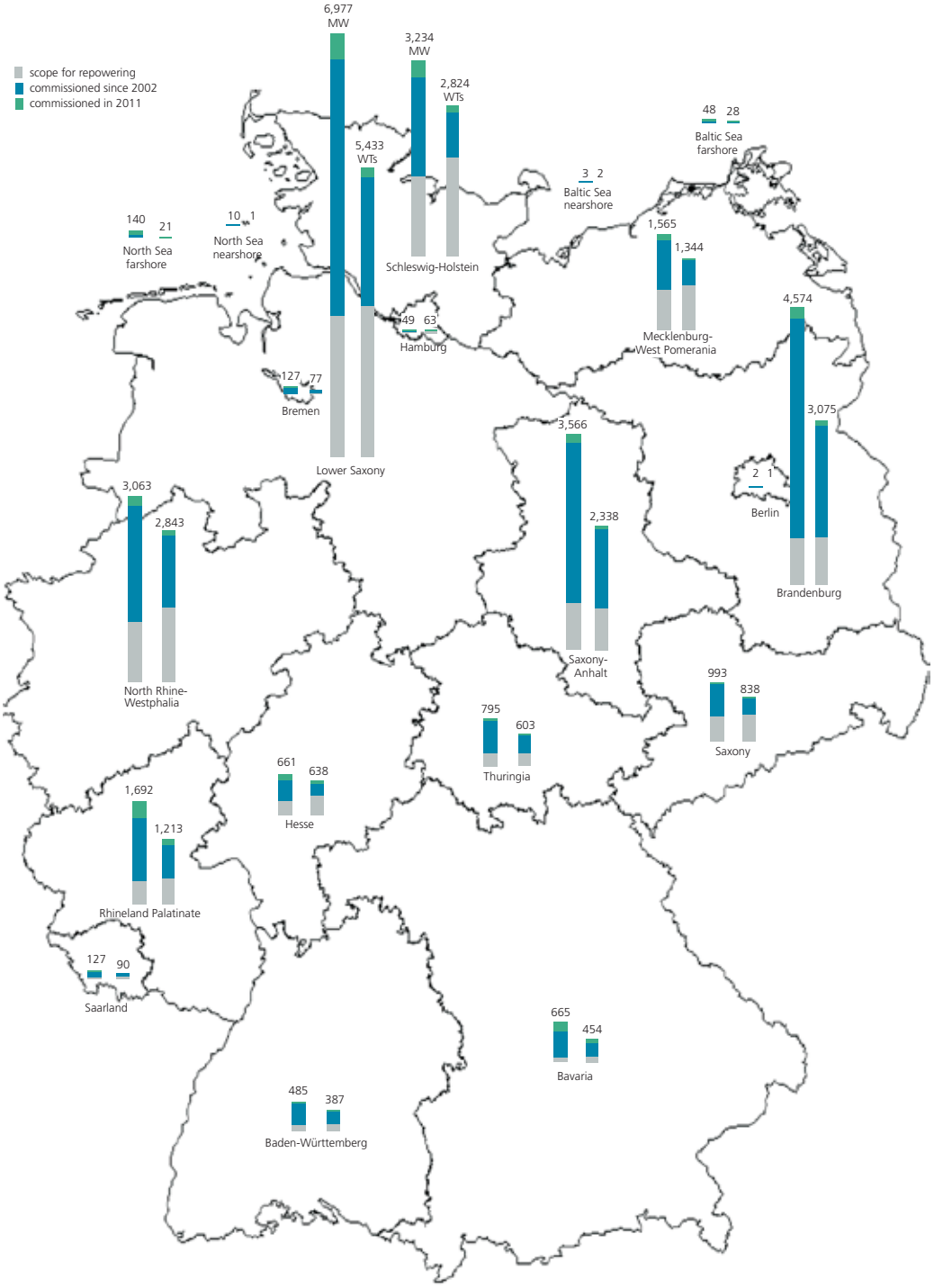


Figure 5: Total nominal power and number of wind turbines in each of the German states and in the North Sea and Baltic Sea (farshore and nearshore), with indication of new installations and suitability for repowering. Data source: IWET

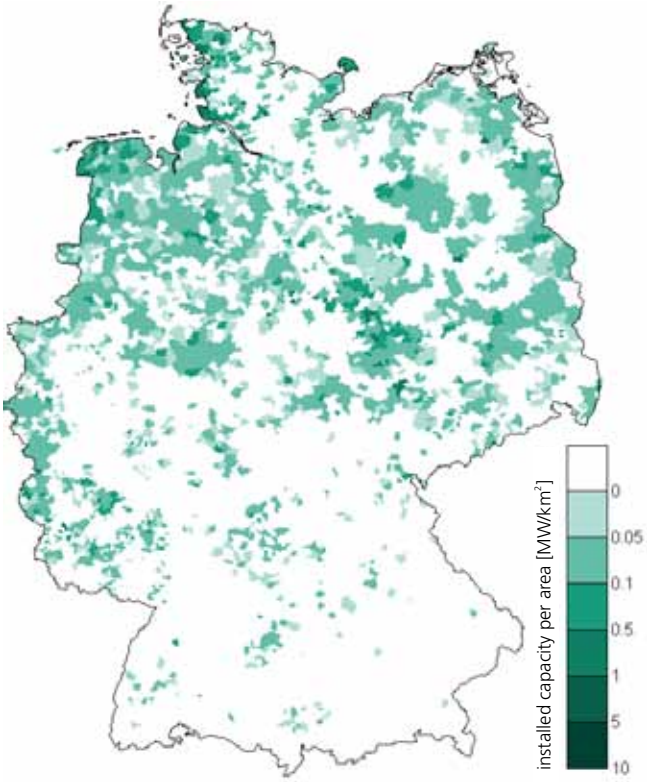


Figure 6: Regional distribution of onshore wind power generation capacity in Germany in 2011 for different postcode regions. Data source: IWET

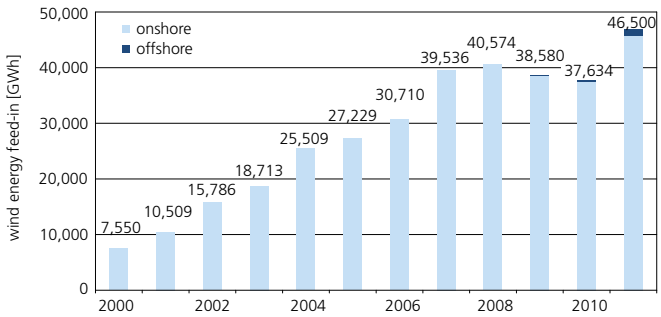


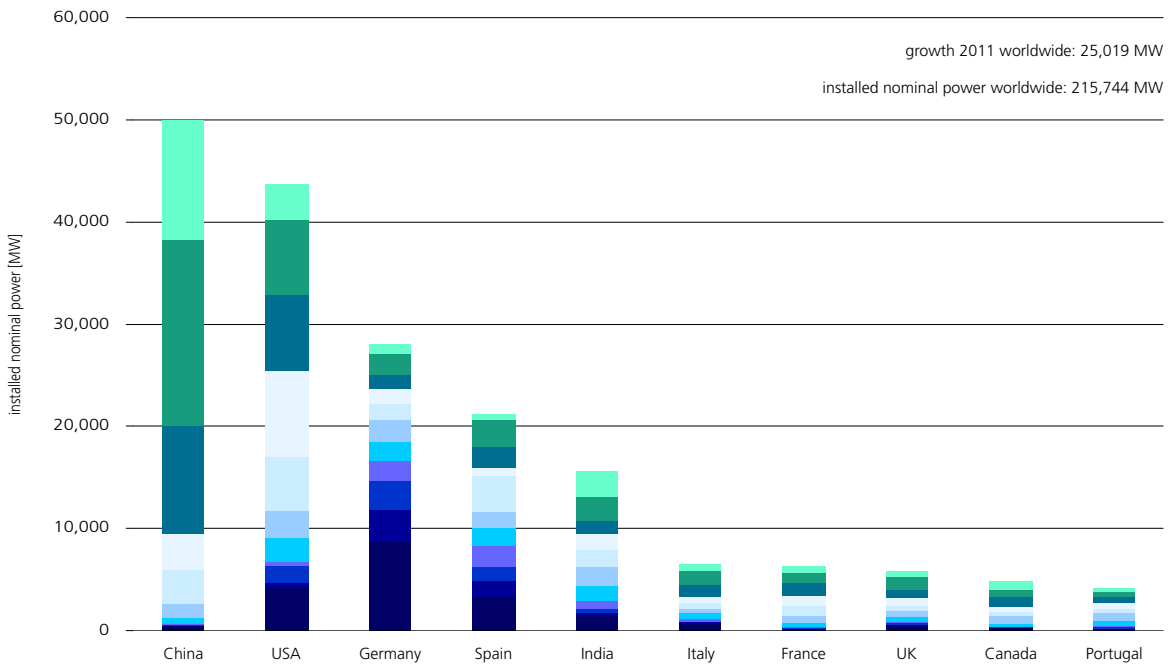
Figure 7: Development of wind energy feed-in in Germany. Data source: BDEW, "Renewable energies and the Renewable Energy Act (2011)", BMU 2012

This is clearly shown in Figure 6, which shows the installed wind power generating capacity per postcode area. The map shows that wind energy is most utilized at the coast, in the north-west, in Saxony-Anhalt, and in east Brandenburg. In the south there is notable wind power generation capacity in Rhineland-Palatinate, in Lower Franconia, and in parts of the Swabian Alb. Information about the potential for wind energy utilization in the individual states is given in the Special Report "Wind energy utilization onshore".

Wind energy utilization. Electricity generation from wind in Germany reached a new record in 2011 at almost 47 TWh. Compared to the poor wind conditions of the previous years there was about a 25% increase in the energy yield. The off-shore wind energy yield amounted around 0.6 TWh and so for the first time made a substantial contribution to the total. Indeed, wind energy covered about 8% of the power requirements of Germany. Figure 7 shows the annual growth in wind energy output from 2000 to 2011.

Growth of wind energy worldwide. During the course of 2011 the nominal power of all the installed wind turbines worldwide exceeded the 200 GW mark and at the end of 2011 was ca. 215,000 MW. The main markets representing about 73.7% of the total were, as in previous years, China, the USA, Germany, Spain, and India. Italy, France, Great Britain, and Portugal are other European countries in the top 10. Their combined market was 10.6%.

The largest growth in 2011 (11,700 MW) was in China. China now has a wind power generating capacity of 50,000 MW and exceeds that of the USA, where 3500 MW of new capacity was installed in 2011 to bring the total to 43,700 MW. The largest growth in Europe was achieved by Germany, with 1900 MW of new wind power generating capacity. In Italy in 2011 this figure was just under 700 MW whilst in France and Great Britain this was about 600 MW, and in Spain and Sweden about 550 MW.



	China	USA	Germany	Spain	India	Italy	France	UK	Canada	Portugal
growth 2011	11,720	3,459	855	526	2,534	696	639	590	792	312
growth 2010	18,280	7,297	2,096	2,734	2,324	1,251	1,031	1,233	714	524
growth 2009	10,500	7,511	1,430	1,940	1,220	1,257	1,228	773	955	674
growth 2008	3,594	8,437	1,353	855	1,678	564	1,057	817	500	550
growth 2007	3,312	5,273	1,625	3,530	1,574	603	901	467	386	434
growth 2006	1,334	2,556	2,195	1,587	1,836	406	699	616	776	692
growth 2005	496	2,390	1,799	1,765	1,451	452	380	445	240	501
growth 2004	198	400	2,019	2,061	863	374	150	193	118	224
growth 2003	98	1,707	2,759	1,372	418	106	93	152	90	105
growth 2002	69	400	3,179	1,495	195	88	62	67	29	67
total Dec 2001	399	4,245	8,671	3,335	1,507	697	85	485	207	127
total 2011	50,000	43,675	27,981	21,200	15,600	6,494	6,325	5,838	4,807	4,210

Figure 8: Worldwide wind power generation capacity. Data source: Wind Power Monthly, 2011. Due to the different data sources, there are differences to other figures cited in this report

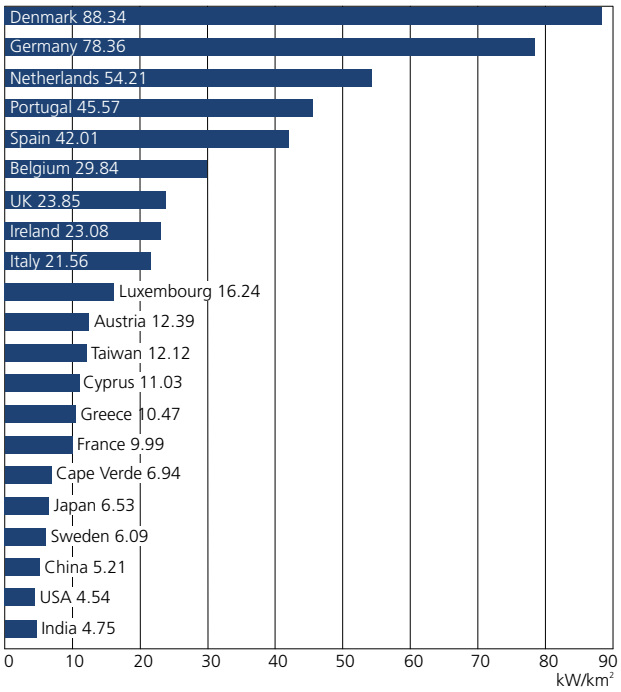


Figure 9: International comparison of installed wind power generation capacity per land area. Data source: The Windicator, Windpower Monthly, 2011

Europe	92,060 MW	43%
North America	48,482 MW	22.5%
Asia-Pacific	71,733 MW	33%
Central and South America	2,402 MW	1%
Middle East & Africa	1,067 MW	0.5%
Worldwide:	**215,744 MW**	**100%**

Table 1: Installed nominal wind power generating capacity in different regions. Data source: Windpower Monthly, 2011. The data do not represent the final data for 2011, but rather a snapshot up to the last quarter of 2011

Germany was for many years at the top of the international league table for wind power generating capacity. In 2008, however, Germany was pushed into second position by the USA and in 2010 into third position by China (see Figure 8).

The largest growth rate in 2011 was noted by Rumania at more than 74%. In China, Sweden, Turkey, Bulgaria, Lithuania, and the Ukraine there were growth rates of between 24% and 30%. Comparing the individual regions, it becomes clear that Central and South America, the Middle East, and Africa are lagging behind with regards to installed wind power capability. Almost 99% of the wind power generation capacity is installed in Europe, the Asia-Pacific region, and in North America (see Table 1).

Germany, with its ca. 72 kW of installed wind power generating capacity per square kilometer, still occupies second place behind Denmark in the international comparison on an area basis (see Figure 9). This figure also highlights that there are huge differences in the installed wind generating capacity in the various countries when considered on an area basis. The relatively populous European countries occupy the first 11 places in the ranking. Large countries such as the USA and China, despite leading the tables for the absolute wind power generating capacity, have considerably lower wind power generating capacity per square kilometer.

STRONG GROWTH IN CHINA

Over the last two years China has become the country with most installed wind power generating capacity. This is largely due to six major wind farm projects in the northern provinces, Inner Mongolia, and in the south-eastern coastal region. The projects involve total nominal powers ranging from 1 GW to 10 GW and over 90% of the wind turbines will be supplied by Chinese manufacturers.

Four of the top 10 wind turbine manufacturers are in China (Goldwind, Sinovel, Guodian United Power, and Mingyang). Their production capacities are also large. Besides supplying the home market, major markets are India and the USA. These manufacturers are also making inroads into the offshore market. For example, Sinovel and Guodian have developed 6 MW wind turbines for offshore use. In 2010 China started up its first offshore wind farm, Donghai Bridge, east of Shanghai. This wind farm comprises 34 wind turbines, each of 3 MW and manufactured by Sinovel, giving a total nominal power of 102 MW. The aim of the National Energy Agency in China is to install 5 GW offshore by 2015.

The marked expansion of wind power in China will also make grid integration there increasingly challenging and wind turbines will have to be increasingly down-powered. In 2011 the National Energy Agency in China set new standards for operational monitoring and the voltage quality for the integration of large wind farms into the grid. The expansion in the individual provinces has been limited. Also, it is planned to fit all wind turbines with low-voltage-ride-through (LVRT) technology.

China mines about 97% of the world's rare earth elements. As such China has a virtual monopoly of the market for neodymium and dysprosium. These elements are required for making permanent magnets which are becoming increasingly important for direct drive wind turbines. In 2009 an export quota was set, and this has been reduced from 50,000 to ca. 30,000 metric tons per year.

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GRID INTEGRATION

Wind energy feed-in 2011. Electricity generation by wind turbines fluctuates with the prevailing wind conditions and in contrast to conventional electricity generation cannot be adjusted to the load pattern. Due to the large number of decentralized wind turbines there are however equalization effects with regard to wind power fluctuation over larger areas.

Figure 10 shows the Germany-wide feed-in of onshore wind energy for the different calendar months. It can be seen that the feed-in in the winter months is generally higher than in the summer months. The feed-in shown in Figure 11 from offshore wind turbines in the North Sea indicates no clear seasonal dependence. When interpreting the offshore data, both the effect of wind turbine failure and the continuing expansion of offshore generating capacity must be taken into account.

The wind energy yield in 2011 was higher than in the preceding years. This was largely due to a very strong December (see Figures 10 and 13). Onshore and offshore a total of ca. 47 TWh of electrical energy was fed to the grid during 2011. Compared to the previous year there was considerably less wind in March and November. July and December had more wind than in 2010.

Daily variations 2011. Figure 12 shows that there were extreme daily variations in the wind energy feed-in in Germany. The highest daily wind energy output was recorded at the start of February. On 5th February the aftermath of Hurricane Lukas resulted in wind energy yield of more than 480 GWh, at an average power of 20,336 MW. At the coast wind speeds of 33 m/s were recorded and at the Brocken (highest peak in the Harz mountain range) there were gusts of up to 43 m/s. However, no major damage was suffered. The day with the least wind was 31 January 2011. The average wind power generation on this day was about 365 MW. On this day about 8.7 GWh of wind energy was fed into the grid.

A drop in power of 1104 MW within 15 minutes on the evening of 26 May was the largest drop in 2011. On this day there were also strong fluctuations in the generated power. The largest

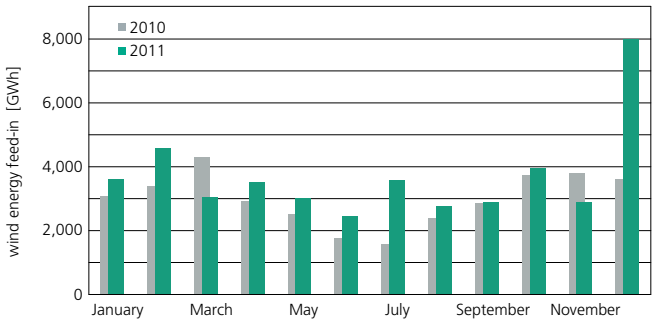

Figure 10: Online extrapolation of the actual feed-in of onshore wind energy in 2011 month by month compared to the previous year, excluding direct marketing. Data source: Published EEG data from EEG-KWK.de and the websites of the TSOs

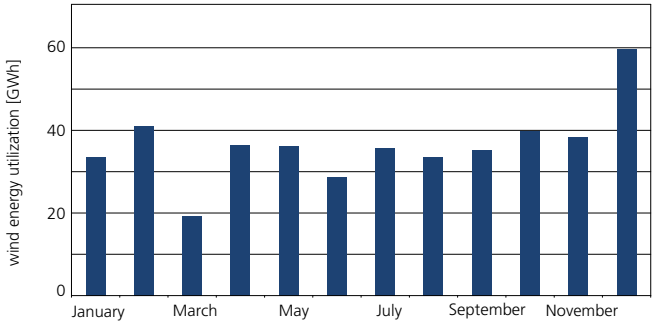

Figure 11: Extrapolation of the actual feed-in of offshore wind energy in 2011 from the North Sea, excluding direct marketing. Data source: Published EEG data from the TSO Tennet

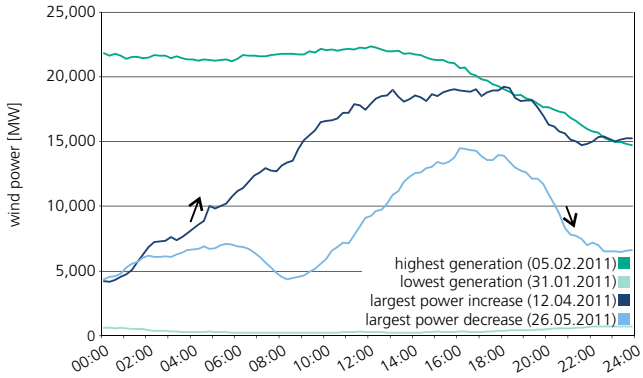

Figure 12: Extreme daily variations in the feed-in of wind energy to the Germany electricity grid in 2011, based on fifteen minute extrapolations of the wind power. Source: EEG data and data of the TSOs

power increase within 15 minutes of 1138 MW occurred in the early morning of 12 April.

Figure 13 shows the average daily variations in the onshore wind energy feed-in to the grid during the summer and winter months of 2011. As can also be seen in Figure 11, the average power production in a winter month is higher than in a summer month. The average wind energy utilized in December, the windiest month, was about 10,750 MW. The daily variations in the summer months have minima in the morning and evening and a maximum around midday. These features are not evident in the winter months.

With regards to offshore wind energy utilization in Germany, such data is only hitherto available for the wind farms in the North Sea (see Figure 14). Due to the comparatively small number and energy output of the wind turbines there, the meaningfulness of the data is limited and can be distorted by a small number of downtimes. In December, the month with the strongest wind conditions, the average offshore wind power feed-in was about 80 MW and the maximum about 110 MW. Although there was no clear trend in the daily variation during the winter months, the feed-in was higher during the summer months at night than during the day. Disregarding the daily variation in the exceptional month of December, offshore wind power has generally less marked average daily fluctuations and less marked differences between the individual months (see Figure 11).

Supply of wind power to the grid. The power duration curve in Figure 15 shows the number of hours over the year when the feed-in from the onshore wind turbines to the grid was above a certain power. The profile of the curve, the area under which represents the total annual wind energy yield, depends on the wind conditions and also the distribution of the latter across the area where the wind turbines are installed.

A minimum of 3750 MW was fed to the German power grid for half of the hours (4380 h) in 2011. Two thirds of the total annual wind energy yield of about 46 TWh was generated in the 2900 strongest wind power production hours.

The maximum available power of 22,860 MW represented ca. 80% of the installed total nominal power. The differing fluctuations in the wind speed and hence power feed-in in the various regions of Germany partially balance themselves out because the wind turbines are spread over a wide geographical area.

Figure 16 shows the power duration curve for the wind farms in the North Sea. A total of more than 430 GWh was fed into the transmission system of TenneT TSO GmbH in 2011. The highest feed-in of the year was achieved in the night from 27 to 28 June. In this period about 129 MW of offshore wind power from the North Sea was fed into the grid.

There are, however, periods when less wind power is generated. For about a quarter of the time the wind power production was below 13 MW (10%). The median wind power production was 48 MW and the average was 50 MW. In the upper quartile, half of the electricity (ca. 220 GWh) was generated during the 2200 strongest wind power production hours.

The power duration curve is surprisingly linear compared to the equivalent graph for onshore wind power generation. One reason for this is the higher and more constant wind speeds expected for offshore locations. A further factor is certainly also the significant expansion in the past year. Only analysis over coming years will definitively clarify the effects of stronger and more stable wind conditions at offshore locations.

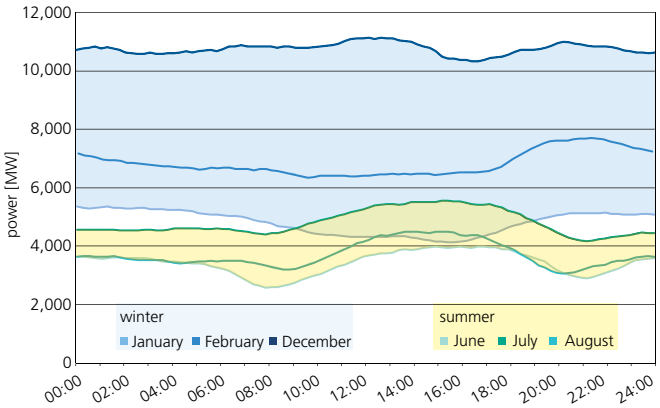

Figure 13: Average daily variation in the onshore wind power feed-in to the German electricity grid during the summer and winter months. Data source: EEG data and data of the TSOs

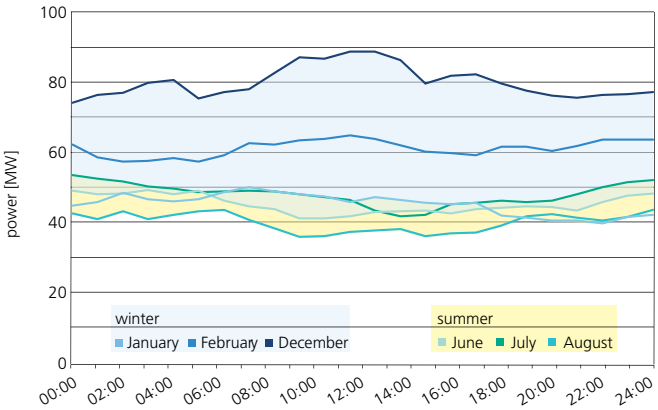

Figure 14: Average daily variation in the offshore wind power feed-in to the German electricity grid during the summer and winter months. Data source: TenneT TSO GmbH and data of the ÜNB

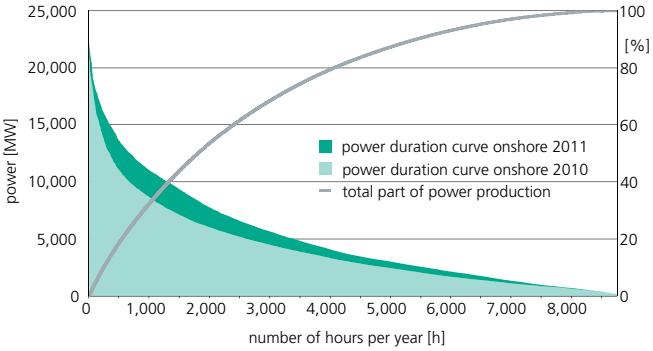

Figure 15: Power duration curve for 2011, Data source: EEG data and data of the TSOs

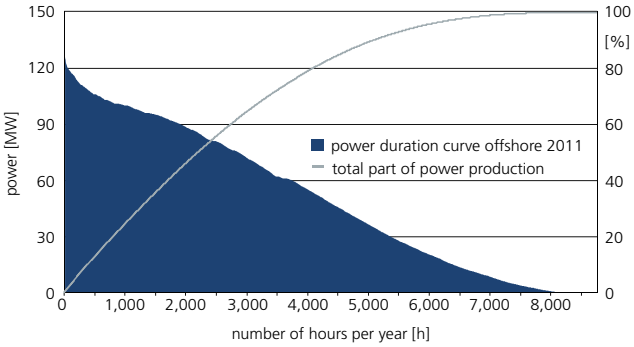

Figure 16: Power duration curve for offshore (North Sea). Data source: TenneT TSO GmbH

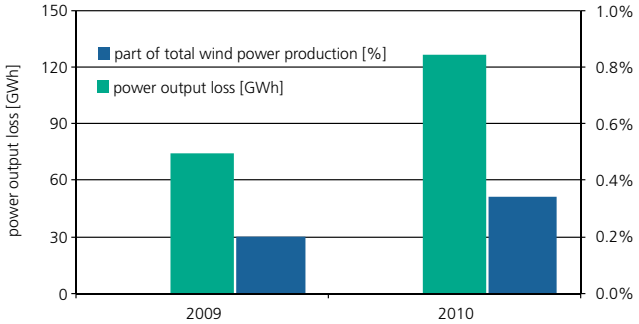

Figure 17: Effects of feed-in management. Data source: Bundesnetzagentur (Federal Grid Agency)

Power feed-in management. Despite the geographical equalizing effects and the priority regulation for renewable energies, there is sometimes overloading of grid capacities which the grid operators deal with by temporarily reducing the feed-in from renewable energy plants (in accordance with the Renewable Energy Act § 11), including wind turbines. Up until now, power feed-in management was mainly carried out in northern and eastern Germany. This topic currently has virtually no relevance for southern Germany. Only in a few regions of central and southern Germany (e.g. Saarland) has power feed-in management been necessary. The need for power feed-in management mainly arose due to overloading of distribution grids and also transmission systems.

Figure 17 shows the effects of power feed-in management on wind energy utilization. In 2010 the energy output loss due to downpowering, about 99% of which can be assigned to wind power, amounted to 127 GWh (74 GWh in 2009). This represented 0.34% (0.2% in 2009) of the total wind energy yield in Germany. This means that the power output loss has increased by 72% within a year. The compensation in accordance with § 12 of the Renewable Energy Act was about 10 million euros (6 million euros in 2009). There is hence an upward trend. The power output loss is likely to increase further in the near future with the further expansion of wind power generation. In particular, the expansion of offshore wind energy utilization and the feed-in to the grid in north Germany will exacerbate this problem. Grid bottlenecks can be alleviated by expanding the grid. Grid expansion up until now has, however, been very slow, even though there have been political initiatives such as Grid Expansion Acceleration Act.

Grid operators. The feed-in of wind power to the grid is carried out in Germany into the four control zones of the grid operators EnBW Transportnetze AG, TenneT TSO GmbH, Amprion GmbH, and 50Hertz Transmission GmbH (see Figure 18). The figure also shows the total nominal power of wind turbines installed since 2002 (onshore and offshore) and the nominal power of newly installed wind turbines (onshore and offshore) in 2011. About 80% of the wind turbines fall under the control zones of 50Hertz Transmission GmbH and TenneT TSO GmbH. Most of the newly installed wind turbines in 2011 were in the control zone of TenneT TSO GmbH. As Figure 19 shows, this impacts the wind power feed-in accordingly in the respective control zones. Whilst the wind power feed-in decreased between 2008 and 2010, the extrapolation for 2011 shows a clear increase again.

Figure 18 also shows the fraction of wind turbines in each control zone that were installed prior to January 2002 and which hence come into question for repowering. The control zone of TenneT TSO GmbH has the largest number of wind turbines that are suitable for repowering.

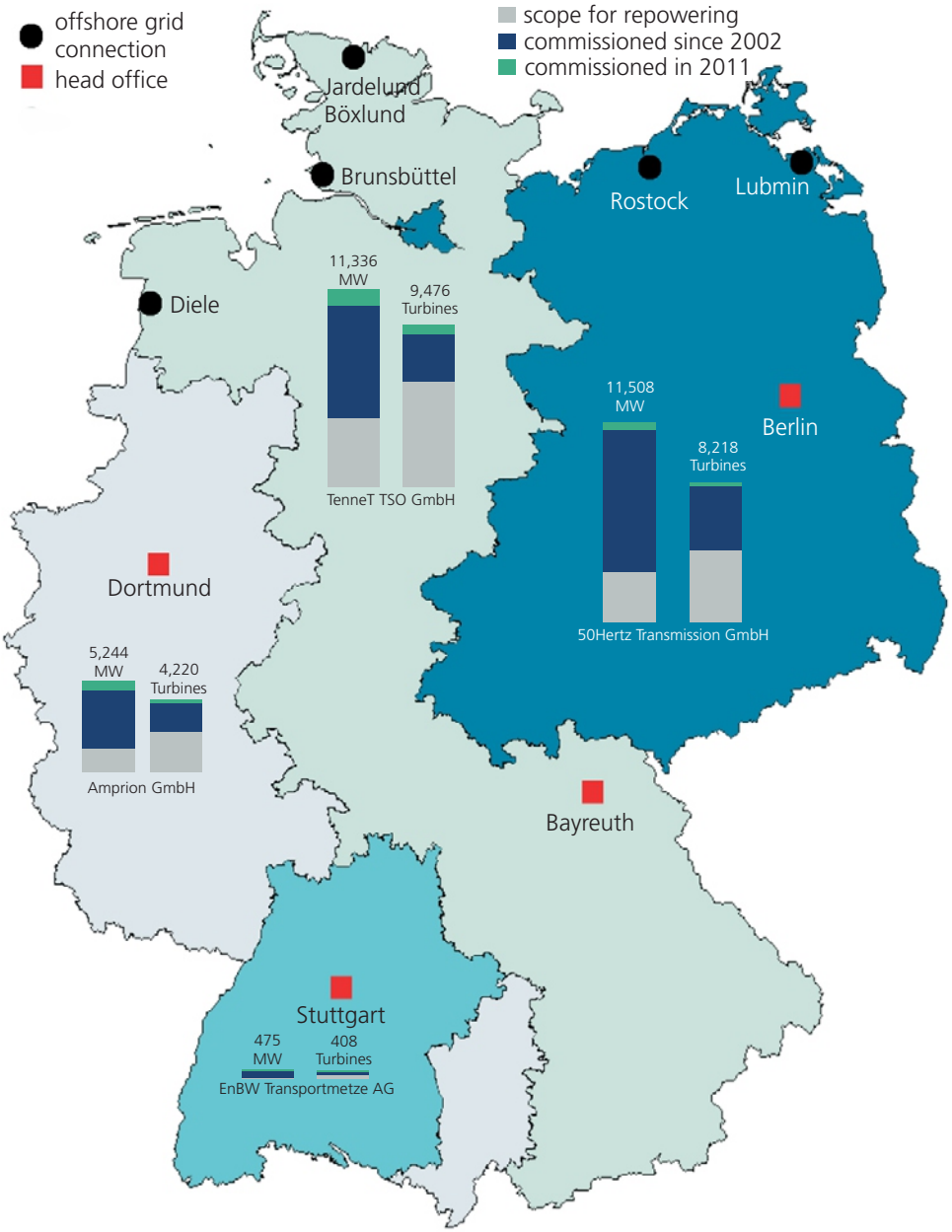

Figure 18: Control zones of the transmission system operators and wind generating capacity per control zone. Data source: IWET

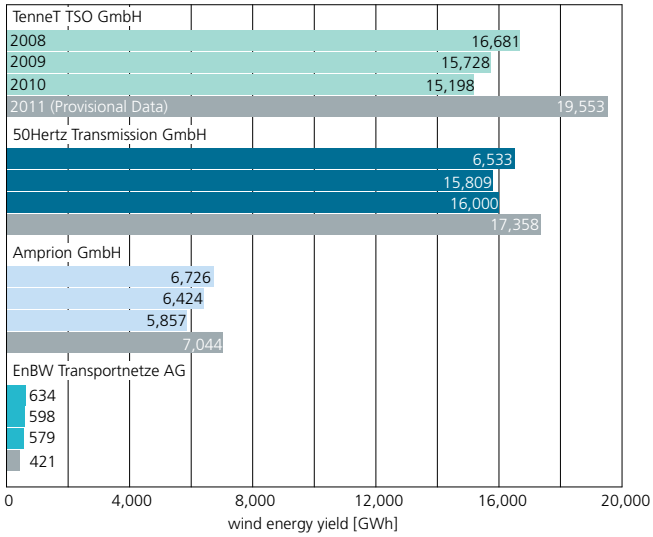

Figure 19: Wind energy feed-in from 2008 to 2011 in the control zones of the four transmission system operators. Data source: TSOs

Connection of offshore wind farms to grids. Offshore wind power is being fed into the grids of TenneT TSO GmbH (North Sea) and 50Hertz Transmission GmbH (Baltic Sea). The Energy Industry Act (EnWG) stipulates that grid connections for new wind farms up to the end of 2015 will be financed and realized by the grid operators. Grid connections will be realized via both high voltage alternating current (HVAC) cables and high voltage direct current (HVDC) cables. The official start-up of the Baltic 1 wind farm in May 2011 marked the first feed-in from a wind farm in the Baltic Sea into the electricity grid. This means that three wind farms (alpha ventus, Baltic 1, and Bard 1) are presently connected to the grid.

Due to the large number of planned and already approved commercial offshore wind farms in the North Sea and Baltic Sea, a connection concept in the form of so-called clusters is favored by the industry for economic and environmental reasons. The realization of this connection concept was considerably simplified in a position paper published by the Bundesnetzagentur (Federal Grid Agency) in the autumn of 2009. This involves a key date regulation, which allows the tendering to be transacted by the relevant grid operators for the clustering of several wind farms planned by different planners.

The position paper was amended early in 2011 with an annex which largely deals with shared grid connections for offshore wind farms.

TenneT TSO GmbH awarded the contracts for the BorWin, HelWin, and DolWin clusters in 2010, and for the SylWin cluster in January 2011. As of October 2011, 13 of the total of 20 submitted applications for approval of investment for grid connection of offshore wind farms had been approved, representing an investment of 5.4 billion euros.

In a letter to the German government dated November 2011 TenneT TSO GmbH pointed out that it believed the deadline for completing the grid connections was at risk due to the high number of connection requests.

Grid expansion on land. The increasing utilization of renewable energies, and in particular wind energy, necessitates expansion of transmission systems. The dena grid study, published in 2005, indicated that by 2015 about 850 km of the high voltage and extra-high voltage grids must be renewed. The dena grid study II, which was published in November 2010, reported the need for much greater additional grid expansion by 2020. This amounts to ca. 3600 km if 380 kV three-phase cables are used and ca. 1700 km if high temperature resistant stranded conductors are used, in each case without storing the non-transmissible power. If using high temperature resistant stranded conductors, the dena grid study II indicates that besides constructing the new lines the reorganization of ca. 5700 km of existing lines is necessary.

According to the Energy Industry Act (EnWG), transmission system operators in Germany are as of 2012 obliged for the first time to present a joint grid development plan. The plan must show what expansion is required for reliable and effective operation of the grid over the coming decade. The basis for drawing up the grid development plan is a scenario framework for development of the electricity generating capacity in Germany over the next decade which takes into account the medium and long term energy policy goals of the German government.

In order to accelerate the grid expansion, the German government passed the Electricity Grid Expansion Act (EnLAG) in 2009. This covers 24 expansion projects, involving 1807 km of lines, which must be urgently realized. As of October 2011, some 214 km were installed. Half of the projects are running late, with delays of one to four years.

WIND ENERGY REPORT GERMANY 2011

ONSHORE

Locations for wind turbines. The viable areas for onshore wind turbines in Germany can be subdivided into coastal regions, the northern German lowlands, and low mountain regions. The viable coastal regions comprise a strip of land about 5 km in width along the north Germany coast. In 2011, as in 2010, there was notable expansion of the wind power generating capacity in the low mountain regions. Indeed, almost as much wind power generating capacity was installed in the low mountain regions (ca. 750 MW) as in the northern German lowlands (816 MW). The new wind power generating capacity in coastal regions amounted to about 330 MW. Put differently, 2011 saw 15.5% of new turbines installed in coastal regions, 43.5% in the northern German lowlands, and 41% in the low mountain regions (see Figure 20 above). Considering the overall current situation, about 17% of the total onshore wind power generating capacity in Germany is in coastal regions, with 55% in the northern German lowlands and 28% in the low mountain regions.

Wind turbine categories. The move towards ever larger wind turbines continues unabated. In 2011, 81% of new wind turbines were in the 2 to 3 MW class. Wind turbines in the 1 to 2 MW class are being squeezed out of the German market. Indeed, wind turbines having nominal powers greater than 3 MW are increasingly penetrating the market and represented 16.8% of newly installed wind power generating capacity in 2011 (6% in 2010).

Model cycles are also becoming longer. Whereas wind turbines having nominal powers up to 500 kW dominated the market for 3 years from 1990 to 1993, wind turbines in the 0.5 to 1 MW class dominated for about five years from 1994 to 1998 before being replaced by the next generation. The 1 to 2 MW class were dominant for almost six years, from 1998 to 2004, and current classes of wind turbines are dominating for even longer (see Figure 20, center).

Direct drive wind turbines are prevalent amongst the wind turbines installed in Germany (see Figure 20, bottom). These wind

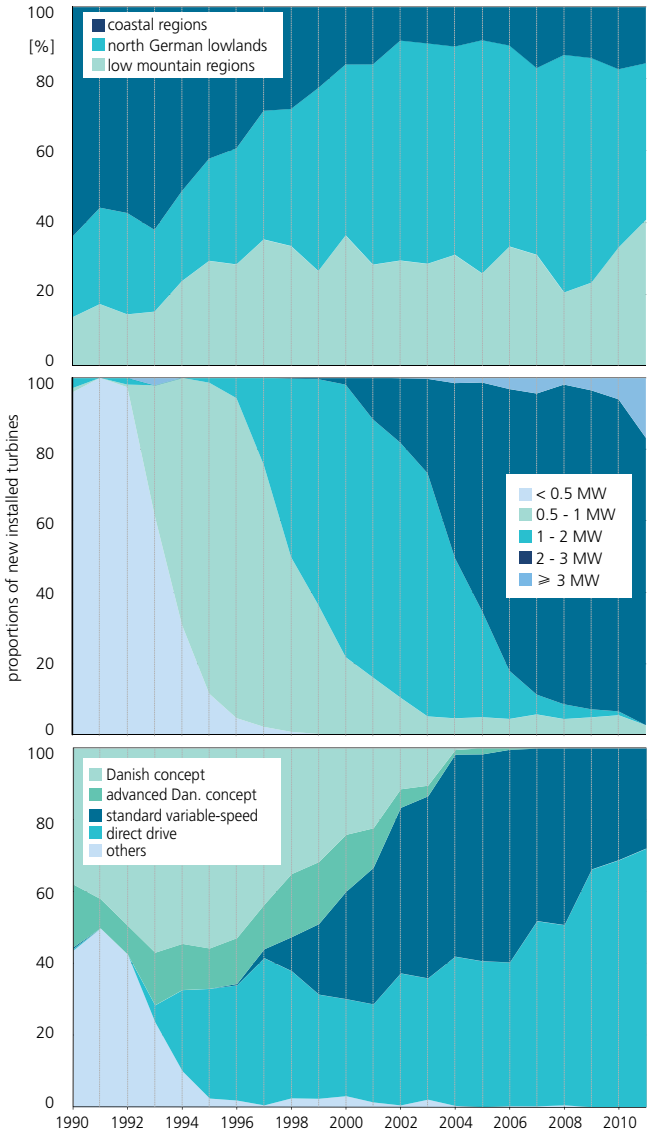

Figure 20: Newly installed wind turbines classified by location, size, and design over the period from 1990 to 2011. Data source: IWET

turbines are almost exclusively produced by Enercon, meaning that 63% of the newly installed wind turbines in 2011 came from this company (see Figure 29). This German company has produced direct drive wind turbines since the mid 1990s and is deemed to be the pioneer of this concept. In the meantime, the direct drive concept has been adopted by other companies and for the most part implemented using permanently excited generators.

Wind turbine size. The power generated by a wind turbine is essentially determined by the diameter of the rotor. This after all determines how much of the wind flow can be converted by the wind turbine into electrical energy. In turn, the energy of the wind flow is proportional to the third power of the wind speed. The latter increases with height above the ground. Also, turbulence decreases with height above the ground. This all means that wind turbines having higher towers can utilize the higher wind speeds there and generate greater electrical power. Figure 21 shows how the average size of newly installed wind turbines has changed from 1990 to the present day. The average tower height of newly installed wind turbines is now more than 105 m. In 1990 the towers were on average only about 30 m high. The average rotor diameter has also increased considerably, from about 23 m in 1990 to more than 83 m in 2011. Although for a long time there was still proportionality between the increasing rotor diameter and hub height, over the last five years the average hub height has increased disproportionally. The reason for this is the increasing exploitation of inland locations for wind turbines. Here suitable wind conditions are only encountered at greater height and wind turbines with towers of typically 130 m plus are being installed.

The surface area of a wind turbine rotor and hence the collected wind energy increases quadratically with the rotor diameter. As can be seen in Figure 22, this fact has a major influence on wind turbine design. Up to a nominal power of about 1000 kW, there is only minor scatter around the trend line. The ratio of rotor area to nominal power, which has a linear influence on the theoretically achievable power output, lies between 2 m² / kW and 3 m² / kW, barring a small number of outliers. In the higher power classes there is a trend to clear differences in rotor diameter, and hence rotor surface area, for the same nominal power. Considering the 2 MW class, for example, the rotor diameter ranges from 66 m to 92.5 m, giving ratios of rotor

DRIVE CONCEPTS AND DIRECT DRIVE WIND TURBINES

The key task of a wind turbine in converting wind power to an alternating current is to convert the rotary motion of the rotor into electrical energy. Although direct drive wind turbines dominate the German market, most other wind turbine manufacturers worldwide make wind turbines with gears. These gear systems convert the rotor speed to a higher generator speed, so allowing compact design of the generator and turbine housing.

Direct drive wind turbines, due to their design, have a generator with a large diameter, meaning high material usage and a greater tower head mass. Wind turbines with permanent magnet generators (PMGs) have this disadvantage to a lesser extent but require the use of rare earth elements (neodymium and dysprosium). The existing mining capacity for these metals is mostly in China. Export is limited by the Chinese government.

In the Special Report "Direct drives and drive-train development trends", Dr. Jan Wenske presents the various drive concepts and outlines their advantages and disadvantages. With regard to new concepts for offshore wind turbines, new emphasis is being put on servicing and maintenance aspects and availability.

Further information can be found on Page 59.

surface area to nominal power of between 1.71 m² / kW and 3.36 m² / kW. This is also evidenced for the new turbines of all classes installed in 2011, with ratios ranging from 1.64 m² / kW to 4.46 m² / kW. It must be borne in mind here that only one wind turbine was installed that had the lowest ratio (Enercon E 126, 126 m, 7500 kW) and likewise only one wind turbine was installed that had the highest ratio (Nordex N 117 / 2400). For the same power coefficient, a wind turbine with a high ratio of rotor surface area to nominal power can attain its nominal power at lower wind speeds. The ratio of rotor surface area to nominal power can be determined for wind turbines in the different regions of Germany. In the coastal region, wind turbines have average ratios of rotor surface area to nominal power of 2.47 m² / kW (2.18 m² / kW for newly installed wind turbines in 2011). In the northern German lowlands this value is 2.61 m² / kW (2.59 m² / kW for newly installed wind turbines in 2011) and in the low mountain regions this value is 2.65 m² / kW (2.65 m² / kW for newly installed wind turbines in 2011).

The hub heights of wind turbines also cover a large range. In 2011, for example, one wind turbine in the 2 MW class was installed with a hub height of 59 m and another with a hub height of more than double that value (138 m). The relationship between the rotor diameter and hub height is shown in Figure 21. However, the location of a wind turbine largely determines the hub height. The two wind turbines mentioned above both had

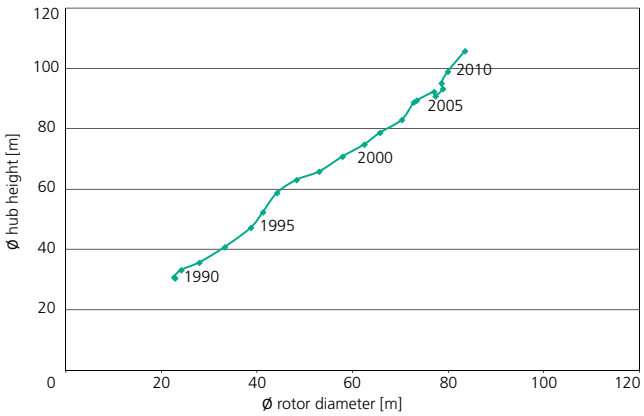

Figure 21: The changing size of onshore wind turbines. Data source: IWET

an identical rotor diameter of 82 m. Up to about the year 2000 the power output per meter of tower was about 11 kW / m, independent of the location of the wind turbines. Since then, though, marked differences have arisen. The relevant values are higher but still similar if one considers all the wind turbines that are installed in a particular terrain category (17.4 kW / m in coastal regions, 16.6 kW / m in the northern German lowlands, and 15.11 kW / m in the low mountain regions). However, the relevant values in those regions for newly installed wind turbines in 2011 are larger and span a greater range (32.3 kW / m, 20.7 kW / m, and 18.9 kW / m respectively).

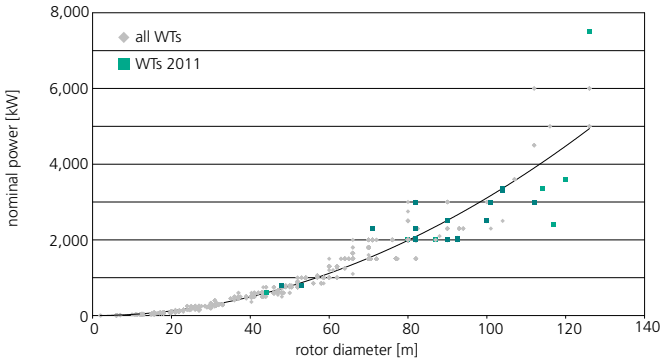

Figure 22: Nominal power as a function of rotor diameter for different wind turbine designs. Data source: IWET

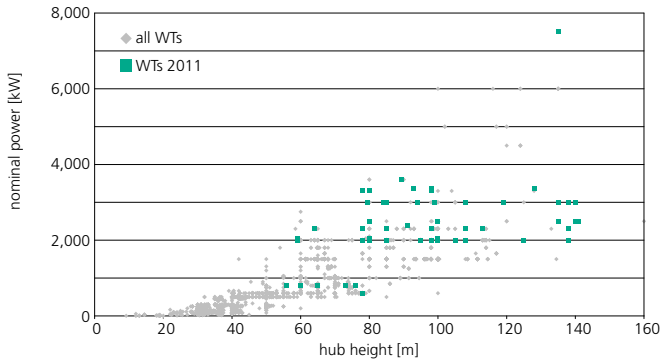

Figure 23: Nominal power as a function of hub height for different wind turbine designs and configurations. Data source: IWET

As shown in Figure 22 and Figure 23, the newly installed wind turbines in 2011 are bigger than ever. The most powerful wind turbine has a rotor diameter of 126 m, a hub height of 136 m, and a nominal power of 7.5 MW. The wind turbine with the highest tower (160 m) was installed back in 2006.

The use of higher towers and larger rotor diameters has gone hand in hand with exploitation of inland locations. The relevant wind turbines here have higher hub heights and rotor diameters but an essentially constant nominal power. At higher heights the rotors can utilize the higher winds there and so be operated more efficiently. Figure 22 and Figure 23 show that the majority of the newly installed wind turbines have larger rotors and hub heights, yet the nominal power remains essentially constant or only slightly increases. At the same time, the wind turbine market is diversifying: the larger the dimensions of the wind turbines, the greater the choice. There is trend towards wind turbines for inland locations with high towers, large rotors, and nominal powers between 2 MW and 3 MW. There is also a trend towards even higher nominal powers, namely larger rotor diameters (up to 126 m) and hub heights (100 m to 120 m).

WIND MEASUREMENT TECHNOLOGY

The exploitation of inland locations using wind turbines with high towers makes detailed knowledge of wind conditions ever more important. The topography inland is more complex and this is especially so in forested areas. Detailed knowledge of the wind conditions at specific locations is hence vital for optimizing the location of wind turbines and the wind turbine design. Wind measurement technology is being advanced in order to procure this information. Measurements using LiDAR, which uses the Doppler effect on reflection of optical signals, have already been successfully used for locations of simple orography.

In the Special Report "New Techniques for Wind Measurement at Fraunhofer IWES", Tobias Klaas presents how LiDAR technology is being advanced for new application fields using comparative values from an additional 200 m high measuring mast. Further information can be found on Page 65.

Figure 24 shows the growth in the average hub height and nominal power of all wind turbines installed in Germany between 1990 and 2011. The average power of newly installed wind turbines was 2.0 MW in 2010 and this increased to 2.2 MW in 2011.

In 1990 about 6 wind turbines had to be built to generate one megawatt of nominal electrical power, new wind turbines today have an average nominal power of over 2.2 MW. In 2002, the year up until now when most new wind turbines have been installed (namely about 2280 wind turbines), the wind turbines had an average nominal power of only about 1.4 MW. Figure 25 shows that the average nominal power of the wind turbines in Germany in 2004 was 1 MW. Although the total nominal power of the wind turbines continues to rise significantly, the number of wind turbines is increasing much more slowly. The average nominal power of the wind turbines now installed is about 1.3 MW.

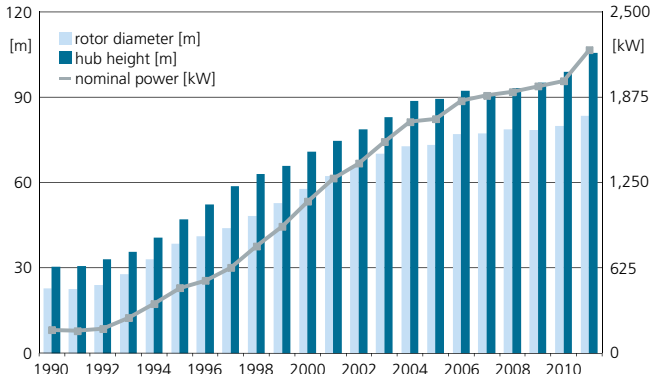

Figure 24: The changing size of onshore wind turbines. Data source: IWET

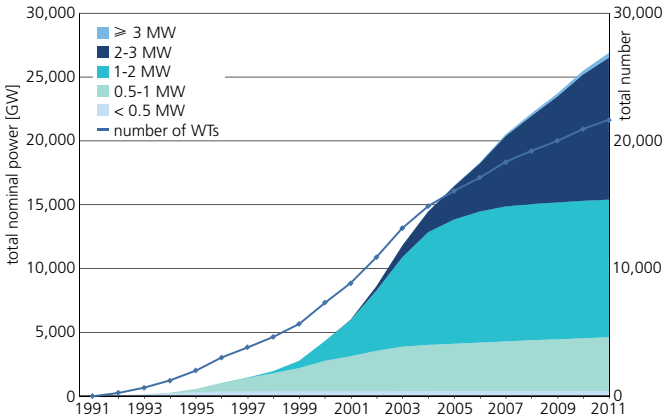

Figure 25: Cumulative onshore wind power generating capacity and number of onshore wind turbines. Data source: IWET

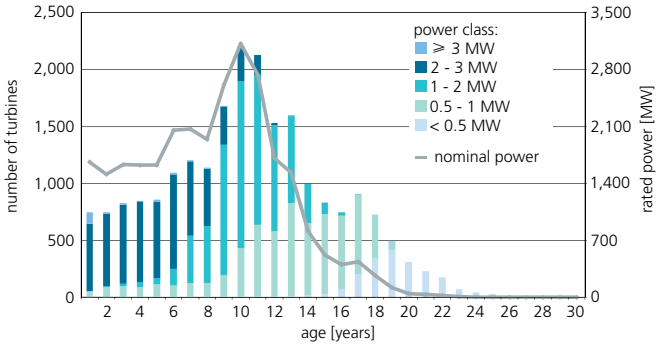

Figure 26: Age structure of wind turbines as a function of the number of turbines and their nominal power. Data source: IWET

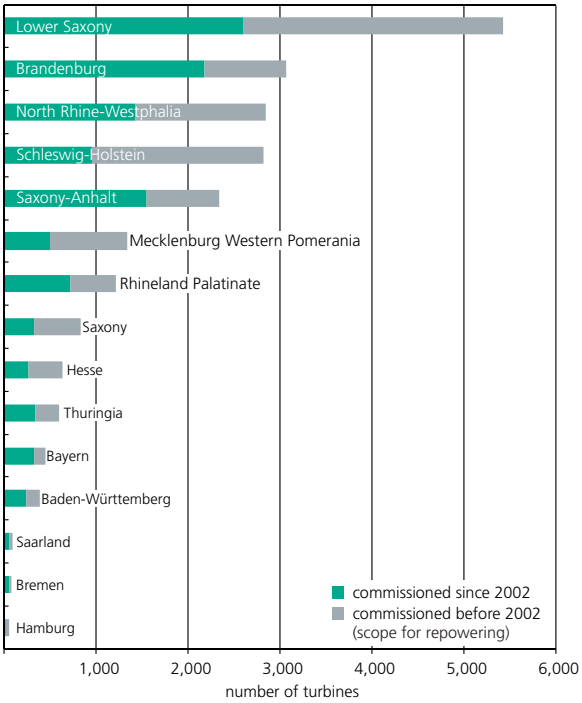

Figure 27: Number of wind turbines suitable for repowering in the different German states (start up prior to 01.01.2002). Data source: IWET

Age profile of wind turbines. Figure 26 shows the age profile of the wind turbines installed in Germany. Some 890 WTs (representing 4% of the total number) have been in operation for 20 or more years and so have already exceeded the generally accepted service life of a wind turbine. The total nominal power of these wind turbines is, however, only 123 MW (about 0.4% of the total nominal wind power of installed wind turbines). The decommissioning of these old wind turbines will hardly have any effect on the total nominal power and will be compensated by a small number of new wind turbines. The decommissioning of old wind turbines, most of which are in coastal regions, will also free up attractive locations for new projects.

The repowering outlined in the Renewable Energy Act targets these locations. The Renewable Energy Act stipulates that all wind turbines brought into operation before 1 January 2002 can be replaced by more powerful new wind turbines in suitable areas. Figure 27 shows how many wind turbines in each of the German states have reached the age for repowering. Lower Saxony and Schleswig-Holstein have 2828 and 1862 wind turbines respectively, representing total nominal powers of 2.3 GW and 1.3 GW, and have the most repowering potential. In Germany as a whole more than 10,000 wind turbines can be replaced by repowering measures.

Wind turbine manufacturers. At the end of 2011 the total nominal power of all the wind turbines installed in Germany amounted to 28,644 MW. The wind turbines themselves were supplied by a large number of companies. Figure 28 shows the market share of the different manufacturers at the end of 2011, on the basis of the installed nominal power and number of wind turbines. Enercon (41% share / 11,600 MW) and Vestas (27% share / 7800 MW) together represent almost two-thirds of the total installed wind power. A similar distribution is found for the absolute numbers of wind turbines.

Up to October 2011, the year saw new wind turbines with a nominal power of 16,814 MW installed worldwide, with about 1923 MW of this in Germany. The wind turbines that were installed in Germany were supplied by different manufacturers (see Figure 29), with Enercon being the biggest supplier (almost 1200 MW / 61% share) followed by the Danish company Vestas (more than 420 MW / 22% share). As such, only a little over a tenth of each megawatt of newly installed wind power capacity was not manufactures by the two largest companies in the marketplace. Many manufacturers with only a small or no presence in the German marketplace have focused their sales activities on fast-growing foreign markets.

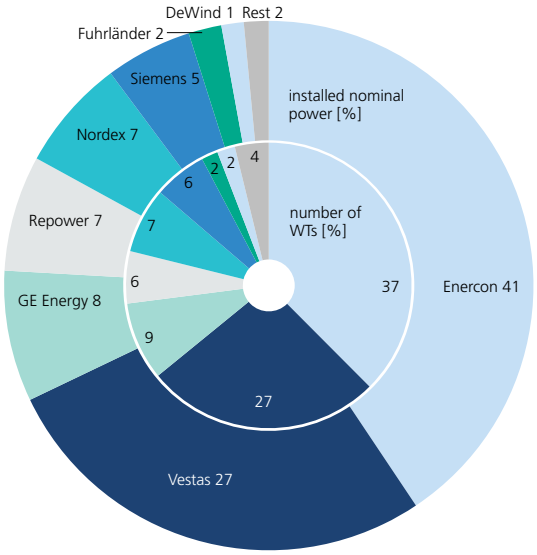

Figure 28: Market share of wind turbine manufacturers in Germany (based on wind turbines in operation up to 2011). Data source: IWET

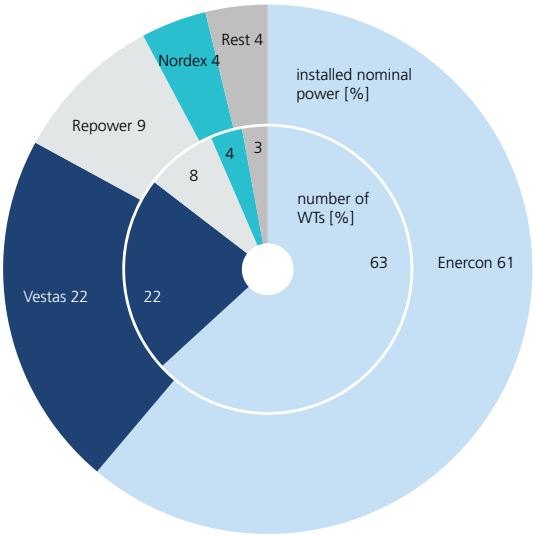

Figure 29: Market share of wind turbine manufacturers in Germany (based on new wind turbines brought into operation in 2011). Data source: IWET

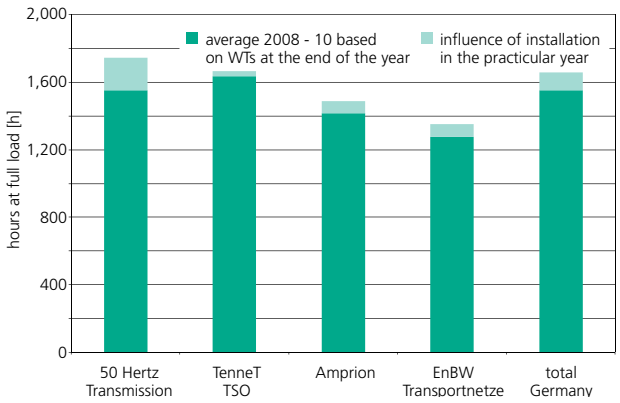

Figure 30: Hours operating at full load in the four control zones of the transmission system operators (2008-2010). Data source: Wind energy yield based on the annual statements of the grid operators pursuant to the REA; Installed wind power generating capacity in each control zone; IWET

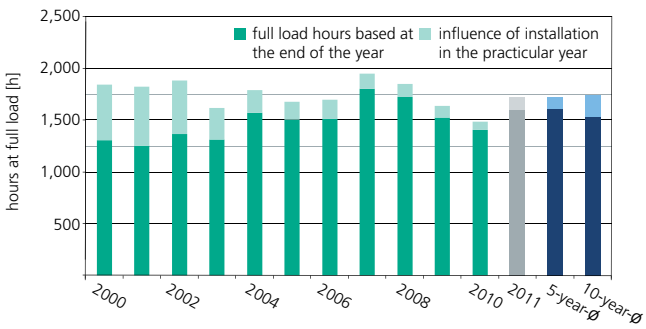

Figure 31: Growth in hours operating at full load in Germany. Data source: Annual statements of the system operators pursuant to the REA; Installed wind power generating capacity; IWET

Hours operating at full load. In order to evaluate and compare the performance of wind turbines, the energy generated per year is often normalized to the nominal power of the wind turbine. The so-called equivalent number of hours at full load depends not only on the performance of the wind turbine but also on the conditions at the location of the wind turbine. High values are achieved in particular at coastal locations. Some wind turbines there even attain values of more than 3000 hours. Values for wind turbines at inland locations are generally considerably lower than this. The electricity generated there is highly dependent on the location and the wind turbine design. High towers and large rotor surfaces allow, however, wind turbines to also be efficiently operated at inland locations.

Figure 30 shows the average value of the hours operating at full load from 2008 to 2010 in the four control zones of the transmission system operators. The average value for Germany lies between 1552 and 1657 hours operating at full load, depending on the assignment of the newly installed wind turbines in a particular year. The wind turbines in the coastal control zones of 50Hertz Transmission GmbH and TenneT TSO GmbH have on average higher hours operating at full load than the wind turbines in the control zones of Amprion GmbH and EnBW Transportnetze AG. The comparatively small number of hours operating at full load in the control zone of EnBW is due to the fact that the wind turbines are installed in the less windy low mountain regions.

As is evident from Figure 31, the hours operating at full load and hence the energy yield of each wind turbine in 2010 was below the value for 2009 and significantly below the long-term average. The preliminary figures for 2011 indicate a significantly higher energy yield, reaching the long-term average value, but still distant from the peak values attained in 2007 and 2008. Exact determination of the hours operating at full load is not possible from the available data. For this reason, the hours operating at full load based on the wind turbines installed at the start and end of the respective year are shown. The range in recent years has got ever smaller due to the decreasing ratio of newly installed turbines to the total number of turbines.

Remuneration for power feed-in. In Germany the feed-in remuneration was formerly regulated by the Electricity Feed-In From Renwables Act (StrEG) which came into force on 1 January 1991. The level of remuneration at that time was at least 90% of the average revenue per kilowatt hour for power supply by electricity supply companies to all end consumers. In April 2000 the Electricity Feed-In From Renewables Act was replaced by the Renewable Energy Act. This has been amended several times since then. The last amendment was approved in June 2011 and came into force in January 2012. Figure 32 shows the present and future remuneration rates.

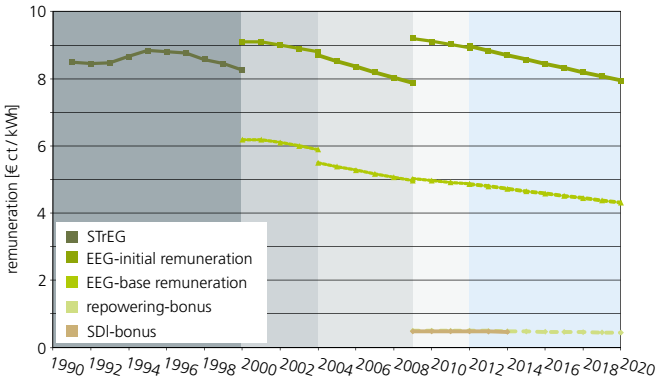

Figure 32: Remuneration of wind energy under the REA

Base remuneration and initial remuneration. In the Renewable Energy Act the minimum remuneration is regulated by a power-dependent level of remuneration, which is defined by a so-called reference yield. For wind turbines that started operation by a certain date an initial remuneration is prescribed for a minimum period of 5 years. Depending on the quality of the wind turbine location, the feed-in remuneration is subsequently reduced to a base remuneration. For wind turbines at very favorable locations the reduction takes place immediately at the end of the fifth year. For wind turbines at locations with poorer wind conditions, the payment at the higher rate is prolonged for two months for each 0.75% less electricity that is produced than 150% of the reference yield. The remuneration rate for new wind turbines also depends on the year of installation. Wind turbines installed in 2012 get an initial remuneration of 8.97 € ct / kWh and a base remuneration of 4.87 € ct / kWh. Under the amendment, the reduction in remuneration has changed from 1% to 1.5%.

Small wind turbines up to a nominal power of 50 kW are exempted from calculating the reference power and receive the initial remuneration over the entire remuneration period.

System service bonus. The initial remuneration increases by 0.48 € ct / kWh for wind turbines that are installed before 1 January 2015 and which at all times meet the requirements of the System Service Regulation. The system service bonus was lowered from 0.49 € ct / kWh to 0.48 € ct / kWh in the amendment, but its duration (originally up to 31 December 2013) was prolonged by a year. Like the base remuneration and initial remuneration, the system service bonus is also subject to annual lowering.

Repowering bonus. In situations where wind turbines are installed as part of repowering measures, a bonus of 0.5 € ct / kWh (0.49 € ct / kWh prior to the amendment) is awarded on the initial remuneration. All wind turbines that were brought into operation before 1 January 2002 are suitable for repowering. The repowering bonus reduces by 1.5% per year. Under the amendment, the power limit of five times that of the wind turbine being replaced was removed. Instead, the number of wind turbines is now limited to the number of previously installed wind turbines. A further condition for undertaking repowering is at least a doubling of the installed power.

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OFFSHORE

Expansion offshore. Although the world's first offshore wind farm at Vindeby in Denmark was commissioned back in 1991, the exploitation of offshore wind energy is just in its infancy. The move from the shore to far offshore is progressing step by step. The first experimental offshore wind farms were constructed relatively close to the shore in rather calm waters, but improved know-how is allowing an ever greater number of wind farm projects to be realized at greater distances from the shore in deeper waters. In order to distinguish these different locations, the terms nearshore and farshore will be used henceforth in this report. As specified in the Renewable Energy Act, a distance of at least 3 nautical miles is used to define a farshore location. This is equivalent to more than 5.5 km from the coast. In the figures which follow, nearshore areas are marked as dotted areas and farshore areas are indicate as solid areas.

Worldwide situation. There are currently 62 offshore wind farms in operation: 34 farshore and 28 nearshore. The 53 European wind farms include 28 in the North Sea, 9 in the Kattegat, 6 in the Irish Sea, and 4 in the Baltic Sea. The 9 Chinese wind farms are in the East China Sea (7) and Yellow Sea (2). At the end of 2011 there were some 1579 offshore wind turbines installed worldwide having a total nominal power of about 4000 MW. Figure 33 shows the worldwide increase in farshore and nearshore wind power generating capacity over time and the Europe/Asia split.

In 2011 some 126 farshore and 129 nearshore wind turbines were newly installed having a total nominal power of over 700 MW (see Figure 34). In Europe, over the last 3 years more than 99% of the new offshore wind power generating capacity was installed farshore. In China, however, nearshore wind farms represent more than 80% of the total (see Figures 33 and 40).

The years 2010 and 2011 proved to be the most successful years up until now with about 2100 MW of newly installed wind power (see Figure 34). According to a study of the European

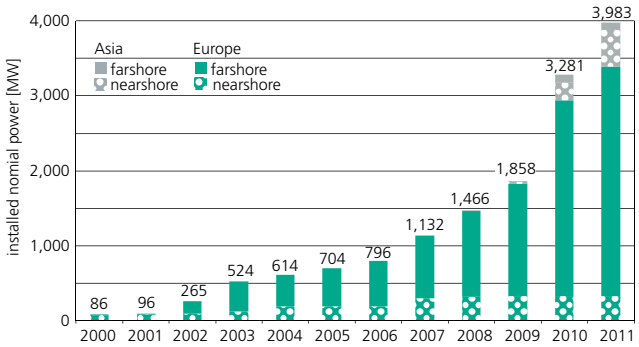


Figure 33: Growth in nearshore and farshore wind power generation capacity worldwide

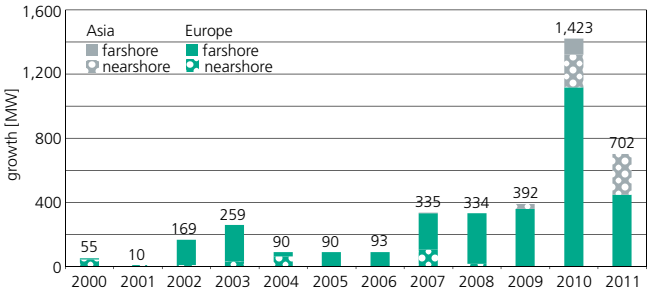


Figure 34: Annual newly installed offshore wind power generation capacity worldwide

Wind Energy Association (EWEA), it should be endeavored to install between 20,000 MW and 40,000 MW of wind power generating capacity in European waters by 2020. In 2011 the total installed capacity was about 3392 MW.

Wind farms in German waters. Various other European countries already have experience of offshore wind energy generation. Germany is focusing on wind farms far out to sea. The German wind farm projects are mostly planned for water depths of over 15 m and at distances from the coast of more than 10 km, so as not to impact the Wadden Sea National Park. The planned locations for offshore wind farms in German

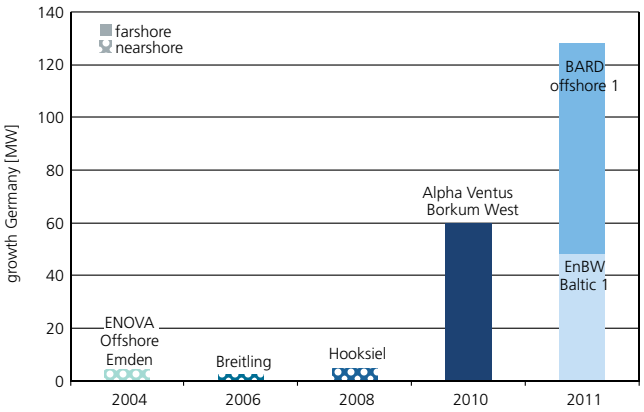


Figure 35: Start-up of German wind farms

waters hence differ considerably from the locations of international offshore projects that have already been realized.

First experience in German waters. The first test wind turbines were installed nearshore (at a distance from the coast of up 5.5 km). The first nearshore German wind energy project was realized back in 2004. Enercon constructed one of the then largest wind turbines (type E 112, 4.5 MW nominal power) in the River Ems at Emden. Since 2006 there has been a Nordex wind turbine at Breitling (Rostock) having a nominal power of 2.5 MW some 500 m offshore at a water depth of 2 m. In the autumn of 2008 a test and prototype wind turbine made by BARD having a nominal power of 5 MW was erected (see Figure 35). This wind turbine is located in the River Jade off Hooksiel, some 400 m from the dyke line at a water depth of about 2 m. This used for the first time a "BARD Tripile I" foundation. The foundation structure is essentially the same as structures designed for actual offshore use.

Situation in Germany. In 2009 the installation of the alpha ventus wind farm marked the start of farshore wind energy utilization. The official opening of the wind farm took place in April 2010. The wind farm consists of 12 wind turbines, each having a nominal power of 5 MW, and is in the North Sea. It is ca. 45 km north of the island of Borkum at a water depth of 30 m, and the total nominal power is 60 MW (see Figure 35).

In April 2011 the Baltic 1 wind farm fed the first offshore wind power to the grid. Baltic 1 is in the Baltic Sea, ca. 16 km north of the Darß-Zingst peninsula, at a water depth of ca. 19 m. The 21 wind turbines made by Siemens have a total nominal power of 48.3 MW (see Figure 35).

The first wind turbines in the BARD offshore 1 wind farm also started feeding the grid in 2011. By the end of 2011, 19 of the planned 80 wind turbines, each with a nominal power of 5 MW in a water depth of ca. 40 m, had been built and 16 had already been connected to the electricity grid. The BARD offshore 1 wind farm in the North Sea covers about 60 km² and lies about 90 km northwest of Borkum.

In September 2011 work started on constructing the foundations for the Borkum-West II wind farm 45 km from Borkum (in the North Sea) at a water depth of 30 m. In the summer of 2012 the final assembly of the first 40 wind turbines will start. This work is scheduled for completion in the winter of 2012/13. The second construction phase for a further 40 wind turbines is planned to start in 2014. The total of 80 wind turbines will supply power of up to 400 MW.

Further expansion in German waters. A large area of the North Sea has already been designated for wind energy utilization (see Figure 36). The expansion of offshore wind energy utilization there will largely occur outside the 12 nautical mile zone. Suitable locations outside this zone are far more abundant in the North Sea than in the Baltic Sea (see Figure 37).

Up until December 2011 a total of 30 wind farms had been approved, 25 in the North Sea and 5 in the Baltic Sea (see Table 2 and 3). The Nordergründe and RIFFGAT (North Sea) wind farms and the Baltic I and GEOFReE (Baltic Sea) wind farms lie within the 12 mile zone, namely in the shore region for which the

relevant German states are responsible for giving approval. The Bundesamt für Seeschifffahrt und Hydrographie BSH (Federal Maritime and Hydrographic Agency) is responsible for approval procedures in the Exclusive Economic Zone (EEZ). Up until now offshore wind farms have been approved for an area covering almost 1160 km² and involving a nominal power of more than 8800 MW (see Table 2, Table 3, Figure 36, and Figure 37). Numerous other wind farms are either planned or are already in the process of being approved.

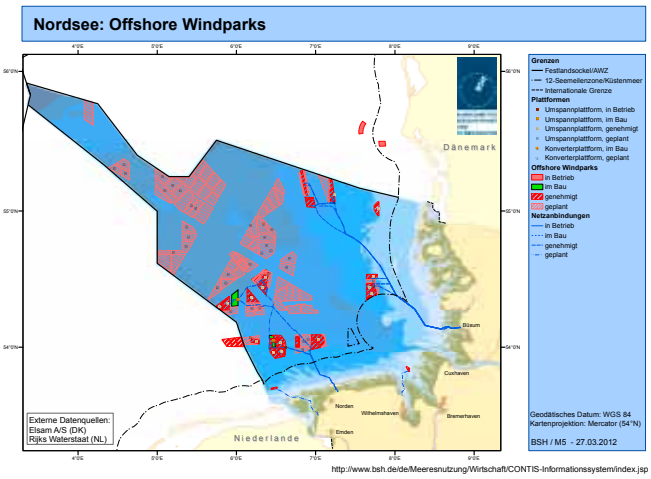


Figure 36: Overview of operational, constructed, approved, and planned wind farms in the German region of the North Sea © Bundesamt für Seeschifffahrt und Hydrographie (BSH) (Federal Maritime and Hydrographic Agency), Hamburg and Rostock 2012

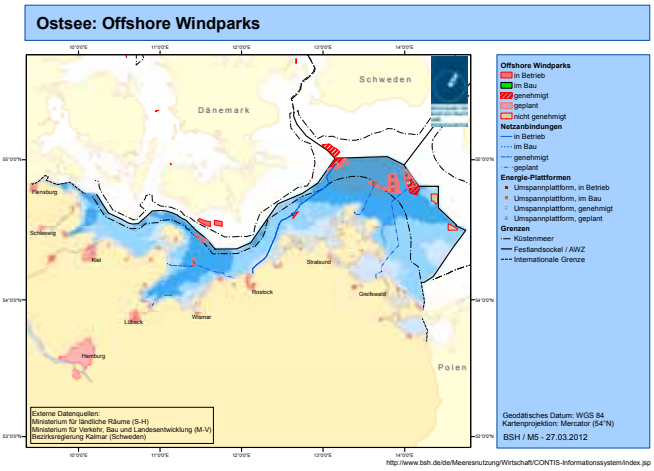


Figure 37: Overview of operational, constructed, approved, and planned wind farms in the German region of the Baltic Sea © Bundesamt für Seeschifffahrt und Hydrographie (BSH) (Federal Maritime and Hydrographic Agency), Hamburg and Rostock 2012

Wind farm name	Planned maximum capacity [MW]	Water depth [m]	Coastal distance [km]	Area [km²]	Status
Arkona-Becken Südost	400	21–38	35	38.4	approved
EnBW Baltic I	48.3	15–19	15	6.9	operating
EnBW Baltic II	320.5	20–35	31	30.1	approved
GEOFReE	25	20	20	1.5	approved
Wikinger	400	29–41	35	33.6	approved
Total	**1193.8**			**110.8**	

Table 2: Approved offshore wind farms in the German region of the Baltic Sea (status as of Dec 2011, BSH, IWES)

Wind farm name	Planned maximum capacity [MW]	Water depth [m]	Coastal distance [km]	Area [km²]	Status
Albatros	400	40	105	39	approved
alpha ventus	60	28–30	43	6.4	operating
Amrumbank West	400	20–25	36	31.9	construction in progress
BARD offshore I	400	39–41	89	58.7	partly operating
Borkum Riffgrund I	231	23–29	34	35.6	approved
Borkum Riffgrund West	280	29–33	50	29.6	approved
Borkum West II	400	22–30	45	55.5	approved
Butendiek	240	20	37	33.1	approved
DanTysk	400	21–33	70	65.8	approved
Delta Nordsee I	240	26–34	50	16.7	approved
Delta Nordsee II	198	29–33	40	16.7	approved
Deutsche Bucht	250	40	87	22.5	approved
EnBW ‚He dreiht'	400	39	85	43.3	approved
EnBW Hohe See	400	26–39	90	41.7	approved
Global Tech I	400	39–41	93	41.1	approved
Gode Wind	400	26–33	45	136.4	approved
Gode Wind II	60	28–34	45	99.9	approved
Innogy Nordsee Ost	295	22	30	35	approved
Meerwind Süd Ost	288	22–26	23	22.2	approved
MEG Offshore I	400	25–26	45	45.9	approved
Nordergründe	125	2–18	13	3	approved
Nördlicher Grund	261	25	84	54.5	approved
Sandbank 24	576	30	90	59.7	approved
RIFFGAT	108	18–23	14.5	6	approved
Veja Mate	400	39–41	89	50	approved
Total	**7,612**			**1,051**	

Table 3: Approved offshore wind farms in the German region of the North Sea (status as of Dec 2011, BSH, IWES)

Europe pioneering farshore wind farms. Many offshore wind farms are currently being planned worldwide. Some have already been approved or are in the early stages of construction. In 2010 and 2011 the United Kingdom and China led the way in offshore wind farm construction (see Figure 38). In China more than 80% of the installed wind power generating capacity is less than 5.5 km from the coast in the nearshore region. The Thanet offshore wind farm in the United Kingdom (UK) is currently the world's largest offshore wind farm. It was brought into operation in 2010 and generates a total nominal power of 300 MW. After Thanet come Horns Rev II (209 MW) and Nysted II (207 MW), two Danish offshore wind farms. The BARD 1 wind farm (400 MW), which is still being constructed but which was partially connected to the grid in 2011, means that in the near future Germany will have one the world's largest offshore wind farms. The Sheringham Shoal offshore wind farm (317 MW), which is also partially in operation, is another large offshore wind farm being constructed in the United Kingdom. The largest wind farm to be partially completed in 2011 is called Walney (almost 250 MW) and is also off the coast of the United Kingdom (see Figure 38).

The United Kingdom installed most new wind power generating capacity in 2011 (more than 320 MW, 89 wind turbines, see Figure 39). China, after strong expansion in 2010 (306 MW), constructed 128 new offshore wind turbines in 2011. Of this total, some 250 MW was installed nearshore. Germany with the offshore wind farms Baltic 1 and BARD 1 installed 37 wind turbines and more than 125 MW of generating capacity at a distance of between 15 km and 100 km from the coast. In Portugal the first offshore wind turbines were installed in the WindFloat wind farm. This wind farm is being constructed in three phases and when complete will have a total nominal power of 60 MW. This means that worldwide in 2011 some 250 wind turbines were installed offshore, representing a total nominal power of more than 700 MW.

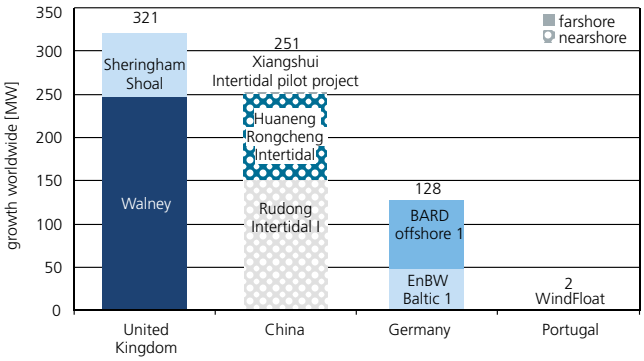


Abbildung 38: Offshore wind farms started up in 2011

ORECCA

The move to alternative energy sources not only involves the transformation of energy generation on land but also the utilization of energy sources in the sea. The potential of marine energy is being researched in the ORECCA research project which is being funded under the EU 7th Framework Programme for Research, Technological Development, and Demonstration Activities (FP7).

The first results indicate that offshore wind is the biggest offshore power source (over 90%). This requires usage of areas of the sea having water depths of greater than 50 m. Wave and tidal power plants can also make useful contributions. The combined usage of wave and wind energy on the Atlantic coasts of Ireland, Great Britain, and France is also being discussed.

Further information can be found in the Special Report entitled "ORECCA – Offshore Renewable Energy Conversion Platforms Coordination Action" by Jochen Bard on Page 71.

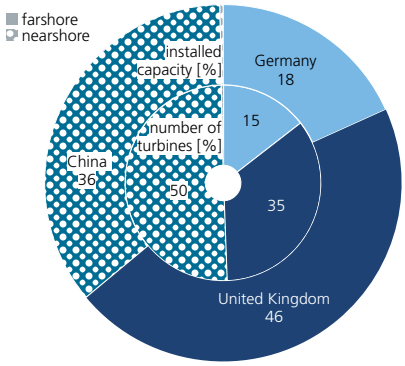


Figure 39: New offshore wind power generating capacity started up in 2011 worldwide

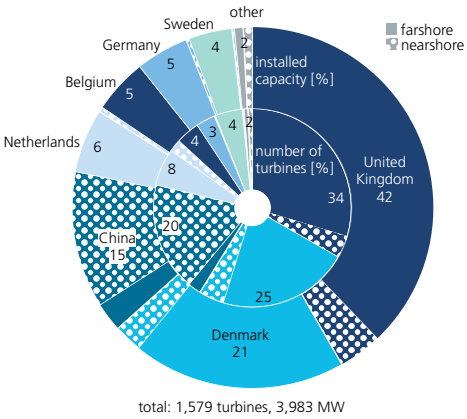


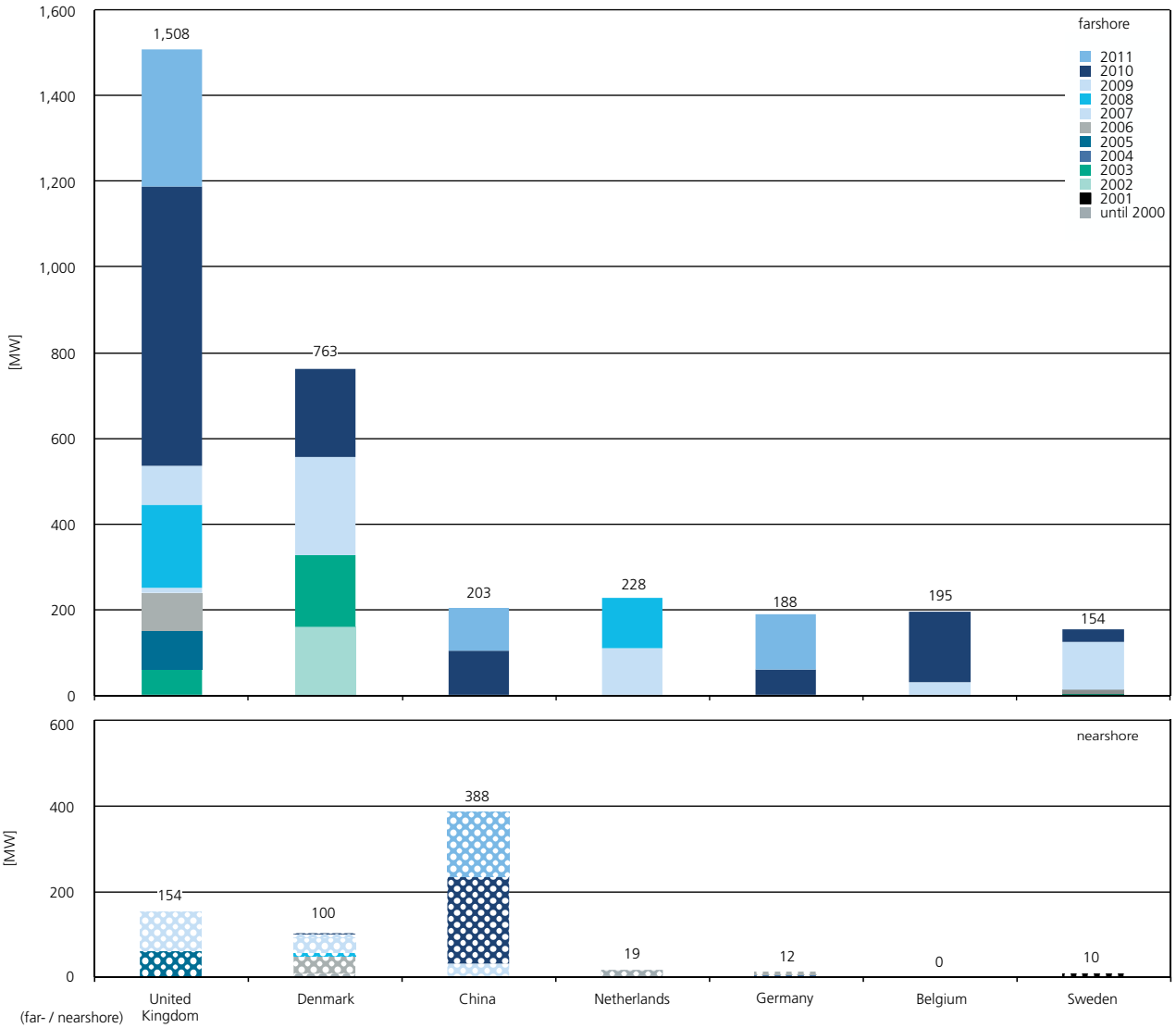
Figure 40: Total offshore wind power generating capacity worldwide (status as of 2011)

In 2011 a total of 11 countries (10 EU countries and China) generated offshore wind power (see Figure 40). Many other nations are installing offshore wind turbines. France and Spain will in 2012 in all likelihood generate their first offshore wind power. In 2012 a high quantity of new offshore wind power generating capacity is expected to be installed in the United Kingdom (ca. 1050 MW) and in Germany (ca. 320 MW).

Europe is currently leading the way in offshore wind energy utilization. Outside Europe, offshore wind farms are only found in China. 2013 will see the first offshore wind farm in the USA connected to the electricity grid and many other wind farms are being planned there.

When countries are compared, Denmark has long played a pioneering role. The first large commercial offshore wind farm was built there. Today there are 404 offshore wind turbines in Denmark having a total nominal power of 860 MW. The United Kingdom has since 2009 had the most installed wind power generating capacity and at the end of 2011 this amounted to more than 1660 MW. However, other countries are catching up. In China there are already 314 wind turbines, representing a total nominal power of 590 MW. Countries such as Norway, the USA, and Canada are also planning offshore projects over the coming years.

Figure 41 shows the growth in offshore wind energy utilization in the 7 leading countries. The bars in the upper diagram indicate the growth in farshore wind power. Very evident is the marked growth in farshore wind power generating capacity in the last 3 years, amounting to more than 2100 MW. The bars in the lower diagram, representing the nearshore wind power generating capacity, show that China was the recent leader here with 388 MW. In the last 3 years many wind turbines have been installed off China's shores, meaning that China now occupies position three in the country ranking of offshore wind power generating capacity.



(far- / nearshore)	United Kingdom	Denmark	China	Netherlands	Germany	Belgium	Sweden
growth 2011	321 / -	- / -	99 / 152	- / -	128 / -	- / -	- / -
growth 2010	653 / -	207 / -	102 / 204	- / -	60 / -	165 / -	30 / -
growth 2009	90 / -	230 / 7	- / 32	- / -	- / -	30 / -	- / -
growth 2008	194 / -	- / -	- / -	120 / -	- / 5	- / -	- / -
growth 2007	10 / 90	- / -	2 / -	108 / -	- / -	- / -	110 / -
growth 2006	90 / -	- / -	- / -	- / -	- / 3	- / -	- / -
growth 2005	90 / -	- / -	- / -	- / -	- / -	- / -	- / -
growth 2004	- / 60	- / -	- / -	- / -	- / 5	- / -	- / -
growth 2003	60 / -	166 / 34	- / -	- / -	- / -	- / -	- / -
growth 2002	- / -	166 / 9	- / -	- / -	- / -	- / -	- / -
growth 2001	- / -	- / -	- / -	- / -	- / -	- / -	- / 10
untill 2000	- / 4	- / 50	- / -	- / 19	- / -	- / -	14 / -
total 2011	**1,662**	**862**	**591**	**247**	**200**	**195**	**164**

Figure 41: Country ranking for offshore power generation capacity

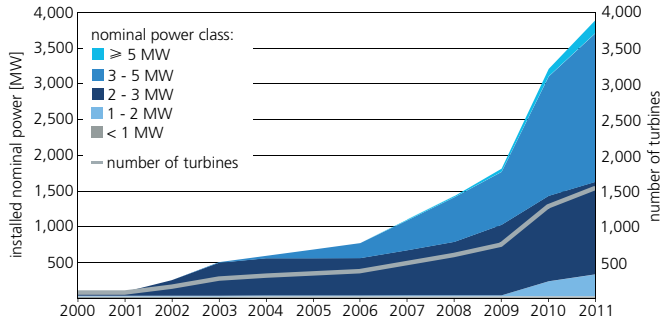


Figure 42: Cumulative growth in offshore power generation capacity worldwide

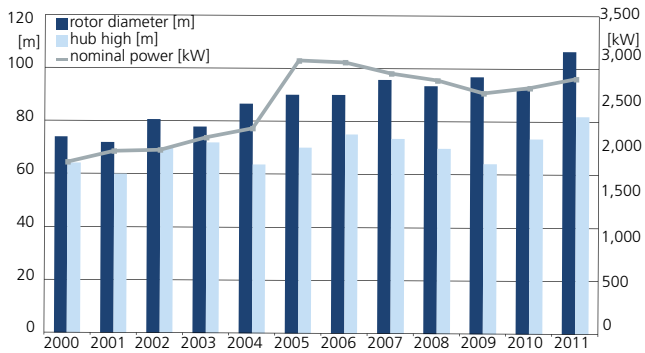


Figure 43: The changing size of newly installed offshore wind turbines

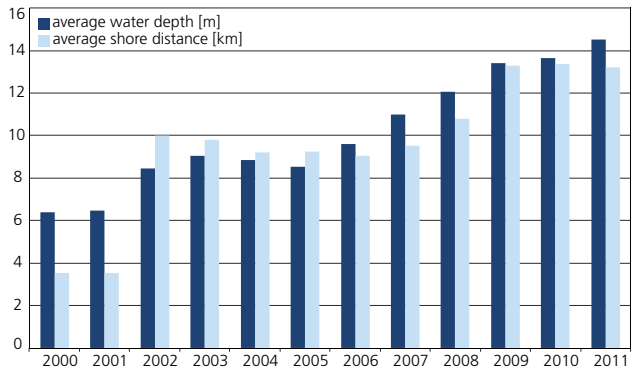


Figure 44: Change in the average distance of offshore wind turbines from the shore and change in installation depths over time

Wind turbine size. In 2000 offshore wind turbines had an average nominal power of 1 MW. Today the average is more than 2.5 MW. Although the total nominal power continues to rise significantly, the number of wind turbines is increasing much more slowly (see Figure 42). This is due to the trend towards multi-megawatt wind turbines. In the meantime there are already 37 wind turbines of 5 MW nominal power in offshore locations. These are all in Europe, namely in Germany (29), Belgium (6), and United Kingdom (2).

The average nominal power of newly installed offshore wind turbines has risen from 1.9 MW in 2000 to 2.8 MW in 2011. The average nominal power has fallen slightly compared to 2005 and 2006 (see Figure 43). In China the nearshore wind farms have mostly wind turbines of smaller nominal power (1.5 MW to 2.3 MW). In the last three years alone, 272 such wind turbines have been installed. The high growth in the number of these new wind turbines means that there is a slight decrease in the average newly installed wind turbine power between 2005 and 2011.

The increasing exploitation of offshore locations allows high power generation at low hub height. The average hub height offshore (80 m) is lower than onshore due to the relative low roughness of the sea surface.

Distance from the coast and water depth. The first offshore wind turbines were constructed 1.8 km from the coast in water depths of 2 m to 4 m (low tide - high tide). With increasing experience, however, ever more projects were realized further from the coast at greater water depth (see Figure 44). Back in 2002 the average offshore wind turbine was 10 km from the coast in 8.4 m of water. Nowadays the average offshore wind turbine is 13.2 km from the coast at a water depth of 14.5 m.

German offshore wind turbines are on average 51 km from the coast at a water depth of ca. 28 m (see Figure 45). When

counties are compared, Germany's wind turbines are furthest from the coast. The challenge of constructing wind turbines in deep waters has also been taken up by, in particular, Norway and Italy. Back in 2008 a pilot wind turbine was installed 20 km from the Italian coast in the Mediterranean Sea and brought into operation. This is a two blade wind turbine having a nominal power of 80 kW which floats at a water depth of ca. 108 m. After a short period of operation, the wind turbine was disconnected from the grid in 2009. In Norway in 2009 the first prototype of a floating wind turbine was installed at a water depth of over 200 m. Hywind is 10 km from the coast of Karmøy in southwest Norway.

Figure 45 shows the average distance from the coast and water depth of offshore wind turbines in Europe. Norway's only offshore wind turbine at a water depth of 200 m is not shown in the graph for scaling reasons. Following Norway, the greatest average water depths are found for Portugal (50 m), Belgium (30 m), and Germany (28 m). Germany (51 km) and Belgium (44 km) have the largest average distances from the coast. The smallest average distance from the coast (1.8 km) is found in Finland. Offshore wind turbines at the smallest average water depth are found in Ireland (ca. 5 m). The wind farm furthest from the coast (more than 110 km) is in Germany. The test wind turbine at the greatest water depth (220 m) is in Norway. A reliable description of Chinese wind farms cannot be given in this report due to the incomplete data regarding water depth and distance from the coast.

The exploitation of locations ever further from the coast and at ever greater water depths is being accompanied by the development, testing, and installation of various foundation structures. Whereas in the early stages only gravity and monopile foundations were used, nowadays seven different foundation structures are in use. In addition to the high-rise-pile cap used in China, jacket, tripile/tripod, and floating foundations are being used (see Figure 46).

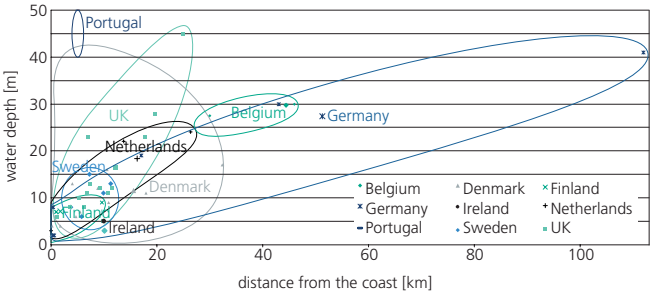


Figure 45: Water depth and distance from the shore of offshore wind farms in different European countries

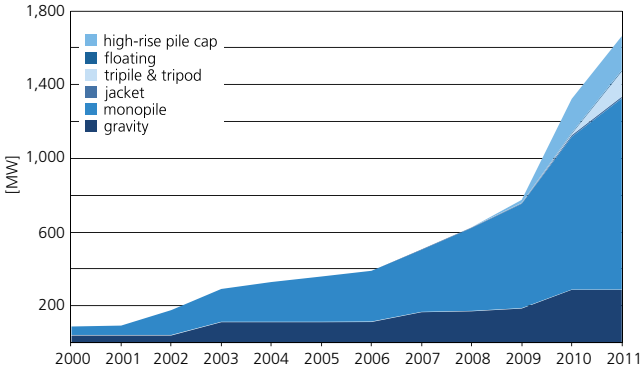


Figure 46: Use of different foundation structures for offshore wind turbines over time

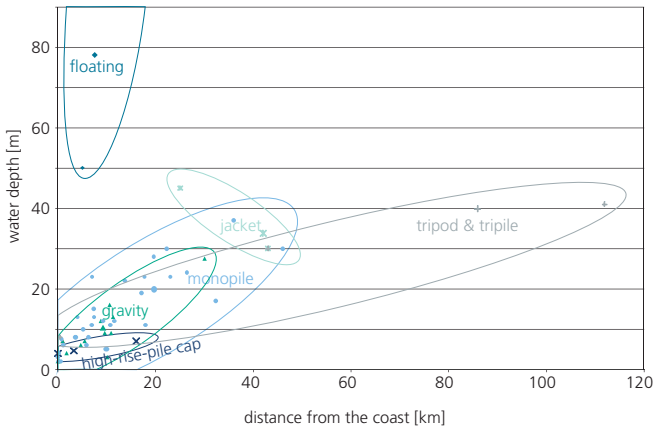


Figure 47: Water depth and distance from the shore of different foundation structures

FOUNDATION STRUCTURES

One of the special challenges for offshore wind energy utilization is the development of safe, reliable, environmentally compatible, and economically viable foundation structures for wind turbines at sea.

Offshore locations are being exploited in ever deeper waters and at ever greater distances from the shore. In an international comparison, German offshore wind farms are playing a pioneering role and many are in water depths of over 20 meters. Gravity and monopile foundations predominate near the shore, but more complex support structures such as tripods and tripiles are necessary at greater water depths.

In order to aid the development and testing of these foundation structures, a test stand is being constructed at the Fraunhofer IWES in Hannover which will enable dynamic tests to be carried out.

Further information about the features of the different foundation structures is given in the Special Report "Support Structures" by Dr.-Ing. Ernst on Page 75.

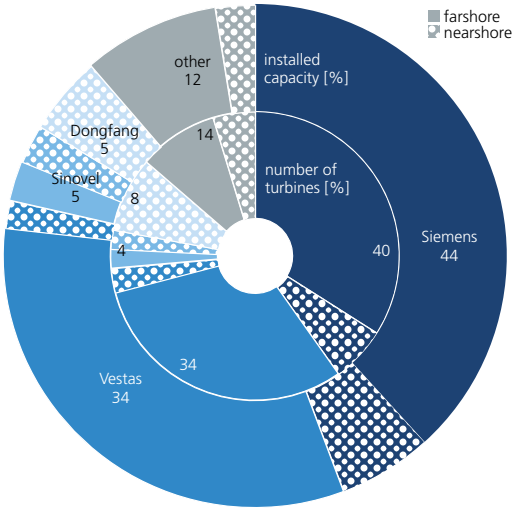
Foundation structures. Although there is no direct correlation between the foundation structure type and country, Figure 47 shows that there is a significant relationship between foundation structure and water depth (and distance from the coast). The exploitation of offshore locations in ever deeper waters means that the foundation structure is becoming ever more important. Gravity foundations, monopile foundations, and high-rise-pile caps are mostly used nearshore in calm waters. On average, high-rise-pile caps are used at water depths of 4.6 m some 3.3 km from the coast. These foundations are used in the calmest waters and closest to the coast. It must be pointed out here that high-rise-pile caps are only used in China. Tripod and tripile foundations are used furthest from the coast, on average 85 km out to sea. Floating structures are currently still being trialed but on average are at water depths of 78 m. These have considerable promise though, meaning that over the coming years floating structures should be able to be used in considerably deeper waters. Today one floating offshore wind turbine is already being tested at a water depth of 220 m.

Figure 47 gives an overview of all offshore wind farms and their foundation structures, showing the average water depth and distance from the coast. The number of wind farms with a particular foundation structure can be readily seen. Figure 46 gives the installed nominal power of wind turbines with different foundation structures.

Wind turbine manufacturers worldwide. As of 2011 some 1589 offshore wind turbines are installed worldwide, representing a total nominal power of 3983 MW. Siemens has the biggest share of the offshore market (44%, 639 wind turbines, 1764 MW total nominal power). The Danish manufacturer Vestas also has a large market share. Currently there are 531 Vestas wind turbines offshore, totaling 1365 MW nominal power (34%) (see Figure 48). Other major manufacturers of offshore wind turbines are the Chinese companies Sinovel (5%) and Dongfang Electric (5%). The remaining wind turbines accounting for a nominal power of over 450 MW (12%) come from 15 further wind turbine manufacturers.

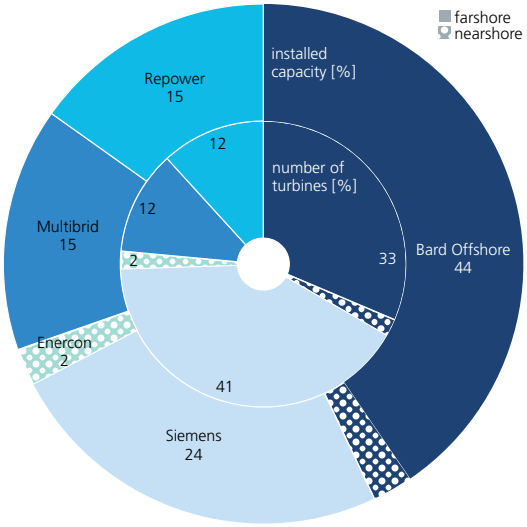
Wind turbine manufacturers in Germany. Up to 2010, Repower and Multibrid supplied more than 80% of offshore wind turbines in Germany, namely for the alpha ventus wind farm. In 2011 this share fell to 30% (see Figure 49). Today BARD Offshore and Siemens have the largest market share (more than 68%). Enercon has a prototype wind turbine installed nearshore (less than 5.5 km from the coast), but at present has no further presence offshore.

External conditions. External conditions offshore are very important. They dictate the wind power that is generated but are also responsible for stresses on the wind turbines. Maintenance work and the accessibility of the wind turbines are also dictated by the external conditions. For these reasons, offshore wind turbines differ from those on land. The high salinity (salt content) of the air and water represents a challenge for offshore wind turbine design: The consequence is aggressive corrosion of the outer walls of the tower, the nacelle, and rotor blades. The high humidity coupled with the high salt content also brings a high risk of corrosion for electrical contacts. Mechanical components are also subject to greater wear due to these extreme conditions. The combination of wind and waves exert huge forces on offshore wind turbines, so that a more robust design is required than for onshore wind turbines.



total: 1,589 turbines, 3,983 MW

Figure 48: Wind turbine manufacturers and their offshore market share worldwide



total: 51 turbines, 198 MW

Figure 49: Wind turbine manufacturers and their offshore market share in Germany

Figure 50: Location of the three FINO measuring stations © FuE-Zentrum FH Kiel GmbH. Illustration: Bastian Barton

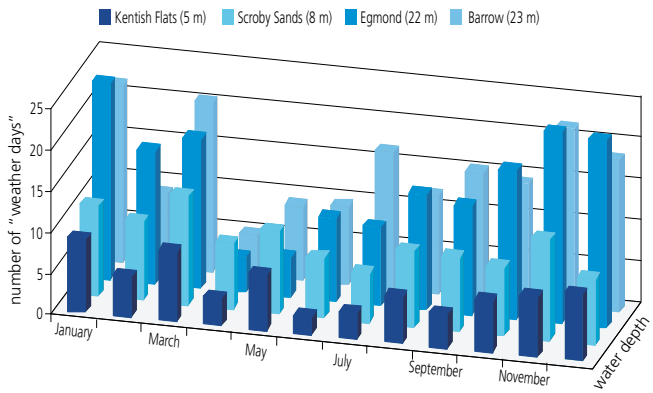


Figure 51: Accessibility of offshore wind farms

Wind conditions. The data from the FINO measuring stations (see Figure 50), which are funded by the German government, show that considerably better wind conditions exist offshore than at even the best onshore locations. FINO 1 measures average wind speeds of 10.1 m/s at a height of 100 m (winter: 11.4 m/s, summer: 8.3 m/s). FINO 2 measures average wind speeds of 9.8 m/s at a height of 102.5 m. The wind speeds in the Baltic Sea at the location of FINO 2 are somewhat lower than in the North Sea at the location of FINO 2. The technical challenges imposed by the prevailing conditions (wave height, currents, salinity) are therefore lower there. FINO 3 is furthest from the mainland, some 80 km from Sylt.

The high wind speeds in principle allow considerably higher energy yield than on land. The offshore wind farm simulated in the dena grid study II attained 3000 to 4500 hours operating at full load depending on the location and wind conditions in the year. Figure 52 shows that such high values have not yet been reached to date in practice by many wind farms.

Accessibility. Unless there is access by helicopter, the wave height largely dictates the accessibility of an offshore location by boat. In general, weather situations when there is a wave height of more than 1.5 m are termed "weather days", because the wind turbine can no longer be safely accessed. The average number of such days is shown in Figure 51 for different offshore wind farms.

Due to the problem of limited accessibility, the existing access systems must be optimized to allow efficient use of offshore wind turbines. Much development work is ongoing to develop systems that are designed for higher wave heights and allow safe transfer of personnel, so allowing the number of "weather days" to be minimized.

Hours operating at full load. Different locations and the performance of the wind turbines there are often compared by normalizing the electricity generated per year to the nominal power of the wind turbines. The resulting so-called equivalent number of hours at full load depends on the performance of the wind turbine and also on the conditions at the location of the wind turbine.

Figure 52 compares the actually achieved hours at full load for wind turbines offshore. The average value for the hours at full load onshore is the average value for wind turbines in all onshore regions in Germany (namely from the coastal regions to the low mountain regions) over the last 10 years. In contrast the data for offshore wind farms come from just a few wind farms and cover various time periods. Data from the alpha ventus wind farm is now available for a full operating year for the first time from a German offshore wind farm. Also due to the very windy conditions in December, the energy yield in 2011 was about 4450 hours at full load and thereby considerably exceeded the expected yield.

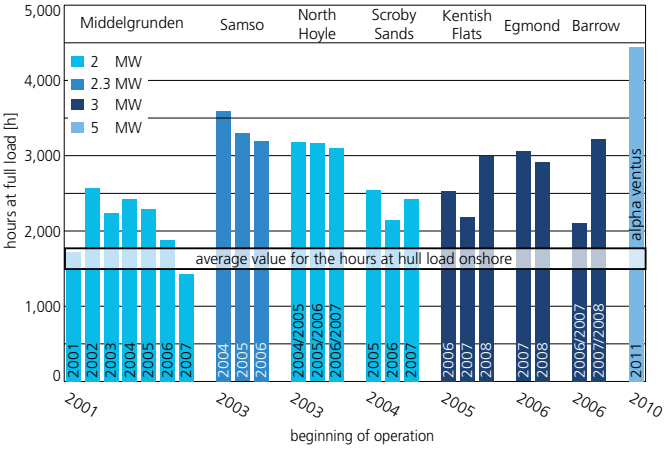


Figure 52: Hours operating at full load of different offshore wind farms

Wind power generation in Germany. Offshore power generation significantly increased in 2011 due to the expansion and new construction of German offshore wind farms (see Figure 53). The figures for 2011 are preliminary and only cover feed-in from wind turbines in the North Sea to the transmission system of Tennet TSO GmbH. The alpha ventus offshore wind farm generated 267 GWh and BARD offshore 1 supplied 171 GWh to the grid. Data is not yet available for the power supplied by the Baltic 1 wind farm to the transmission system of 50Hertz Transmission GmbH.

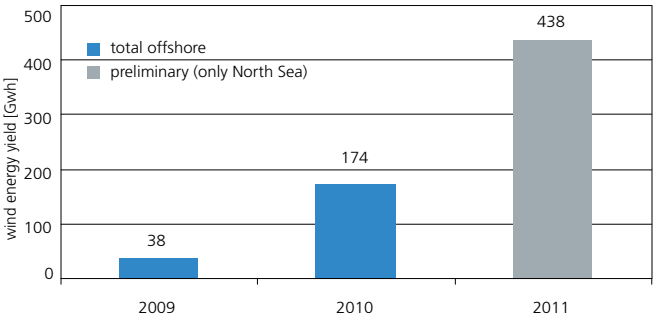


Figure 53: Offshore wind energy yield in Germany (only in the North Sea). Data source: Annual statement pursuant to the REA, Tennet

Reliability. Conclusive statements about the reliability of wind turbines can only be made after many years of operation. Up until now the available information does not allow such parameters to be given for offshore wind turbines. Table 4 gives a first example indication of downtimes at the Dutch wind farm Egmond aan Zee.

It can though be concluded that the primary causes of failure are damage to the gear systems and generators and faults with the pitch and control systems. However, general statements cannot yet be made.

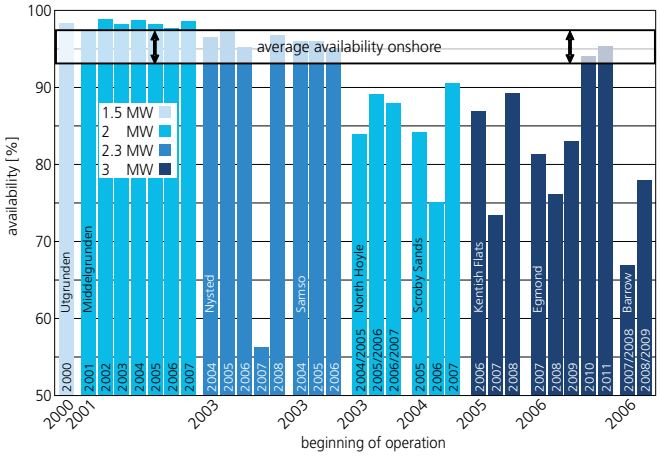


Figure 54: Wind turbine availability over time

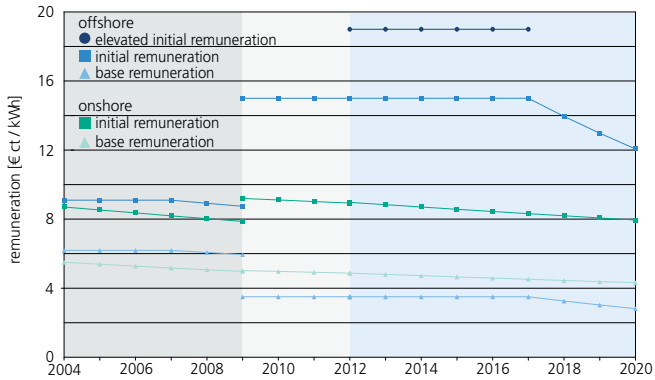


Figure 55: Feed-in remuneration for offshore wind energy

	2007 [%]	2008 [%]	2009 [%]	2010 [%]	2011 [%]
Available Time	82	76	83	94	95,4
Electrical	1	0	0	0	0
Converter	1	1	0	0	0
Control System	2	2	1	1	0.7
Brake System	0	0	0	0	0
Gearbox	9	14	10	0	0.3
Generator	1	4	4	3	0.7
Pitch System	2	1	1	0	0.6
Yaw System	0	0	0	0	0.1
Blade System	0	1	0	0	0.8
Structure	0	0	0	0	0
Grid	0	0	0	1	0.3
Environment	0	0	0	0	0.3
Planned maintenance	2	1	1	1	0.8

Table 4: Downtimes for the Dutch wind farm Egmond aan Zee. Data source: Hoefakker B.; OWEZ Shell, Offshore Wind Farm Egmond aan Zee 5 years of Operation, 2012

Availability. The objective of all maintenance is to achieve high wind turbine availability at as low as possible cost. Modern wind turbines onshore generally have an availability of 95 to 99 percent. The value is usually expected to be considerably less offshore due to the special location and related challenges (e.g. loads, accessibility). This trend is confirmed by the results achieved to date for existing offshore wind farms. Figure 54 shows the availability of different offshore wind farms, ranked by date of start-up. Whilst the older wind farms, consisting of turbines with relatively low nominal power and relatively close to the coast, have availabilities in the region of the average availability of onshore wind turbines, the availability of the more recently commissioned wind farms is much lower.

Remuneration for offshore wind power feed-in to the electricity grid. Since April 2000 the feed-in remuneration has been regulated by the Renewable Energy Act. In order to also ensure profitable operation for offshore wind turbines, the Renewable Energy Act has since 2004 laid down special regulations for wind turbines at sea. Offshore wind turbines are defined here as wind turbines at least 3 nautical miles (ca. 5.5 km) from the shoreline. Instead of the hitherto 4 year cycle, the Renewable Energy Act will in the future be amended every 3 years. The last amendment came into force in January 2012.

The key amendments regarding remuneration for offshore wind power are outlined in Figure 55.

Base remuneration and initial remuneration. To encourage offshore wind power generation in Germany the initial remuneration for offshore wind turbines was increased from originally 9.1 € ct / kWh to a similar level as of other EU countries, namely 15 € ct / kWh. In a countermove, the base remuneration was markedly reduced from 6.19 € ct / kWh to 3.5 € ct/kWh. After start-up of a wind turbine, the initial remuneration is prescribed for 12 years. Thereafter the feed-in remuneration is reduced to a base remuneration. Offshore wind turbines that are brought into operation up to 2017 are remunerated for 12 years with 15 € ct / kWh and then with 3.5 € ct / kWh.

Enhanced initial remuneration. All offshore wind turbines that are brought into operation up to the end of 2017 can apply for an enhanced initial remuneration of 19 € ct / kWh as an alternative to the standard initial remuneration. In this case, the guaranteed period for the initial remuneration is reduced to 8 years. In cases where there is extension of the period of initial remuneration, an extended initial remuneration of 15 € ct / kWh is paid for several years after elapse of the initial 8 year period, and this is followed by payment of the base remuneration of 3.5 € ct / kWh.

Extension of the period of initial remuneration. The time period for the initial remuneration is extended for offshore wind turbines that are constructed at least 12 nautical miles (ca. 22.2 km) out to sea or in water depths of at least 20 m. For each whole nautical mile beyond the 12 nautical miles, the period is prolonged by half a month and for each additional whole meter of water depth the period is prolonged by 1.7 months. Figure 56 shows the length of the period of initial remuneration as a function of the distance from the coast and water depth. Some of the planned wind farms will be able to receive the initial remuneration for a further four years, namely for a total of 16 years.

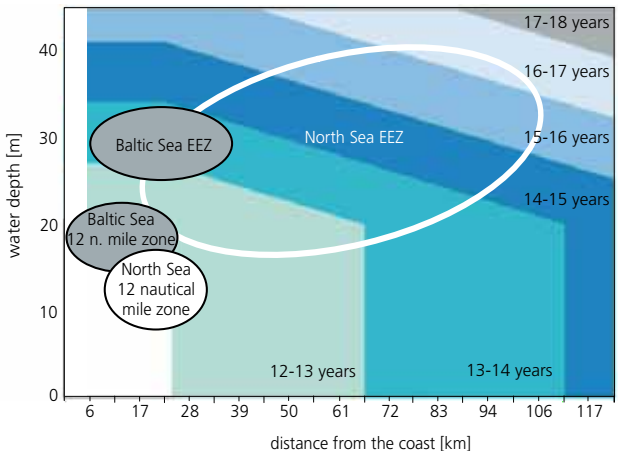


Figure 56: Duration of the initial remuneration for offshore wind turbines in Germany

Investment. Significant acceleration of the expansion of offshore wind energy is a priority. In order to expand offshore wind power to reach a total of 25 GW by 2030, about 75 billion euros must be invested. As this concerns a relatively new technology, the investment risks are difficult to estimate. In order to have improved understanding of the technical risks associated with offshore wind energy and hence facilitate the financing, the construction of the first 10 offshore wind farms will be promoted. For this the Kreditanstalt für Wiederaufbau (KfW development bank) will in 2011 initiate a special program entitled "Offshore Wind Energy" with credit amounting to a total of 5 billion euros at market rates. In August 2011 the KfW development bank announced that the contract to finance the Meerwind Ost and Meerwind Süd (288 MW) offshore wind farms in the North Sea had been signed. In addition, other accompanying measures for the rapid expansion of offshore wind energy will be trialed such as repayable failure guarantees, the sponsoring of special ships under the KfW special program "Ship Financing" and also Hermes loan guarantees in the German external economic zone.

Approval. The Offshore Installations Regulation has been amended to accelerate the approval procedure for wind farms. The amendment came into force in January 2012. Wind farms can now be realized faster because in the future one planning approval procedure, taking account of all interests, will suffice. Up until now, several procedures for the various project sponsors had to be completed for the same location. In the future, one timetable and action plan will cover the whole process through to start-up of the wind turbine. The planning authority (BSH) has the option of accelerating the process by setting a deadline. In the future, ministries can specify criteria regarding the order of processing applications. If possible, those projects which will feed power to grid soonest will be officially approved first. Here, the proximity to the coast and to power lines are key aspects which will be taken into account.

Electricity generation costs. In general, the technical challenges involved in generating power offshore are greater than onshore. The foundations, cabling, installation, and operation are all more challenging when wind turbines are out to sea. The loads on the wind turbines are also considerably greater and servicing and maintenance work is more complex.

For political and economic reasons it is necessary to quantify the cost of wind power generation in general, and in particular offshore.

Table 5 gives an overview of the cost and electricty production of selected wind farms in Europe. In order to allow comparison between the individual offshore wind farms, the investment costs per kilowatt nominal power (1733 € / kW to 3315 € / kW) and the annual operating costs per kilowatt nominal power (34.2 € / kW to 147.4 € / kW) were normalized to the nominal power of the wind farm. The large differences between wind farms are partly due to the widely differing boundary conditions. On the one hand country-specific differences can be cited,

Country	No.	Wind farms	Year constructed	Capacity	Investment cost		O&M	Full load hours
				(MW)	(Mio. €)	(€/kW)	(€/kW)	
UK	1	North Hoyle	2003	60	120	1,992	64.7	3,066
	2	Scroby Sand	2004	60	107	1,783	34.2	2,343
	3	Kentish Flats	2005	90	156	1,733	36.4	2,557
	4	Barrow	2006	90	181	2,011	63.5	2,575
Denmark	5	Middelgrunden	2001	40	49.2	1,230	38.6	2,500
	6	Rødsand	2010	207	390	1,883	91.2	3,800
	7	Generic				2,850	77.5	4,080
Netherlands	8	Prinses Amalia	2007	120	398	3,315	147.4	3,350
	9	Generic				3,000	90.1	3,350
Germany	10	Alpha Ventus	2010	60	194	3,230	122.1	3,700

Table 5: Investment costs, operating costs, and energy yield for selected offshore wind farms

for example in Germany the grid operators bear the costs for grid connection, and on the other hand the wind farms have different locations, for example different distances to the coast, water depths and foundation structures. For these reasons, comparison of offshore wind farms is usually not worthwhile and no general statements about costs can be made.

One of the most important and interesting parameters for evaluating offshore wind energy is the electricity generation costs. The specific electricity generation costs (in € / kWh) are calculated as the ratio of the relevant annual costs to the amount of electricity generated in that year. The annual total cost is the sum of the individual cost items, whereby the investment costs are assigned to the individual years taking into account the relevant interest rate.

Figure 57 shows the theoretical electricity generation costs under different boundary conditions. The two levels represent different operating costs. Operating costs are a decisive cost factor and are difficult to estimate at sea. They cover several aspects such as costs for maintenance, maintenance contracts, repairs, insurance, multiservice contracts, management, tax, and electricity purchase. The hours at full load lie between 1000 and 5000 hours. The specific investment costs (1000 € / kWh to 4000 € / kWh) and operating costs (30 € / kWh to 150 € / kWh) cover a wide range in order to include as many scenarios as possible. The ten offshore wind farms in Table 5 are shown on the graph for example purposes and can be identified by their numbers. The electricity generating costs calculated using this approach range from 2.5 € ct / kWh to almost 50 € ct / kWh, the latter only arising under very unfavorable conditions.

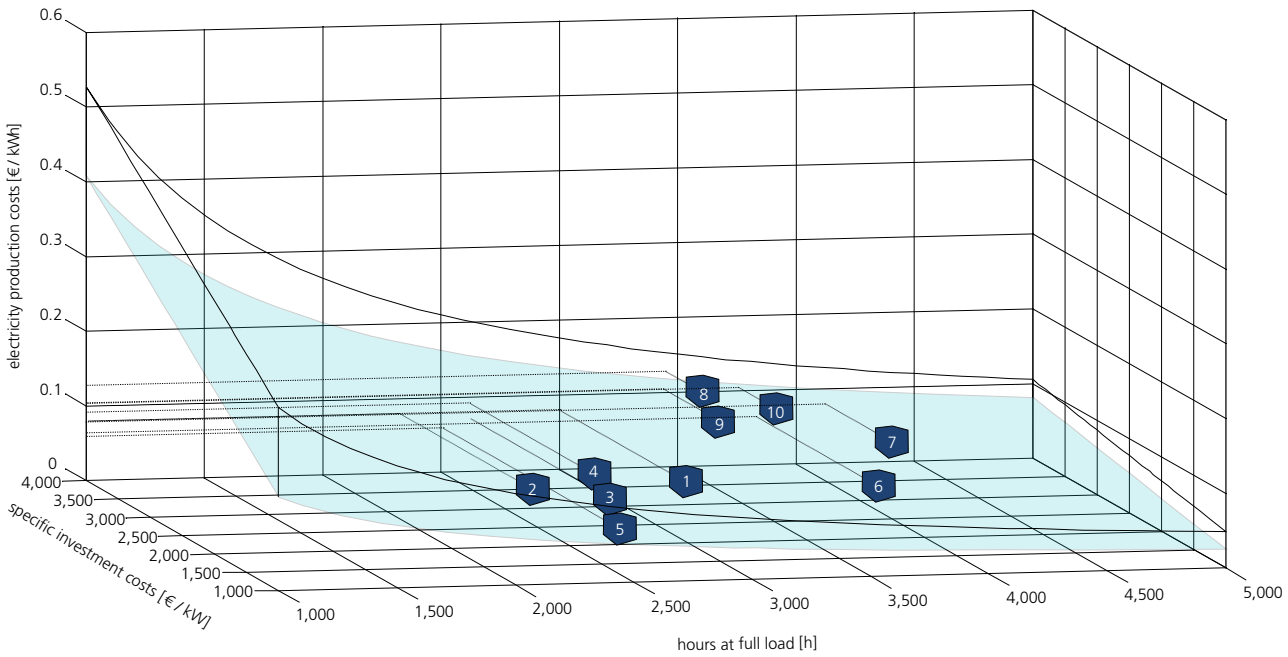


Figure 57: Electricity generation costs as a function of the specific investment costs, hours operating at full load, and annual operating costs compared with the initial remuneration (pursuant to the REA) for offshore wind energy

WIND ENERGY REPORT GERMANY 2011

SPECIAL REPORT

Wind energy utilization onshore - wind conditions and suitable locations

Written by Dr.-Ing. Stefan Bofinger – stefan.bofinger@iwes.fraunhofer.de

Introduction

Renewable energies will in the future be one of the mainstays of energy provision. In this regard, of ever increasing importance is the matter of where the energy production facilities can be built.

Following the start up of offshore wind energy utilization in Germany and accompanying research programs, this study devotes itself explicitly to onshore wind energy utilization and the identification of suitable locations in Germany for wind turbines. The study was commissioned by the Bundesverband WindEnergie e.V. (BWE) and carried out by Fraunhofer IWES.

The objective of the study was to check the feasibility of the scenario of the BWE (usage of 2% of the land surface) using Geographical Information Systems (GISs). In contrast to previous studies, this study was based on GIS data. The excluded areas and useable areas were identified on the basis of the ground cover and different land usage (e.g. urban areas and infrastructure areas). In order to take account of distance regulations, the excluded areas were where necessary surrounded by suitable buffer zones.

Data basis and methodology

Overview of the methodology

The method essentially involved five steps (see Figure 1). Firstly, areas based on available GIS data were defined which were excluded for geographical reasons (step 1). From the remaining area, the useable area was determined taking into account the assumptions for different land usage, distance regulations, etc. (step 2). For each location the wind conditions were determined (step 3). Wind turbines were sited in the useable areas (step 4) in accordance with the given scenarios. The potential wind energy that could be feed-in was calculated (step 5).

Data basis

The ground cover data [Corine] (resolution 100 × 100 m) and infrastructure data (e. g. roads, railway lines, power lines) and data for special areas (nature conservation areas) originated from the Bundesamt für Kartographie und Geodäsie (Federal Agency for Cartography and Geodesy) [BKG 2003]. In order to calculate the wind energy that could be feed-in, wind data of the German Meteorological Agency [DWD] were used and extrapolated to the relative hub height.

Determination of useable areas

Wind turbines are nowadays usually sited in open fields, away from conservation areas and forests. However, their siting in forests and to a limited extent also in certain conservation areas is conceivable. Studies were hence carried out for the following three scenarios:

1. **Areas without restrictions,** for example agricultural areas
2. **Areas in forests**
3. **Areas in conservation zones,** for example nature reserves, FFH (Flora-Fauna-Habitat)

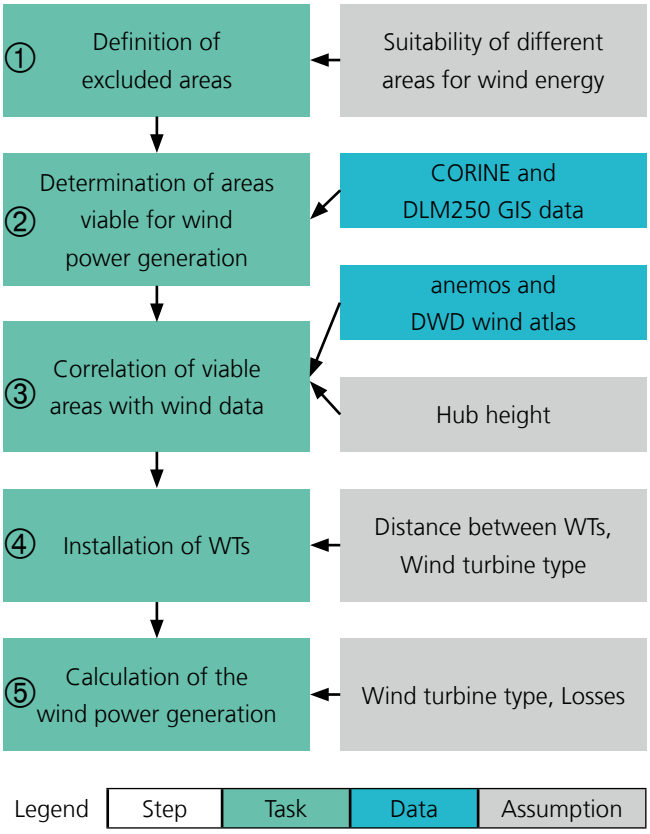


Figure 1: Schematic representation of the procedure

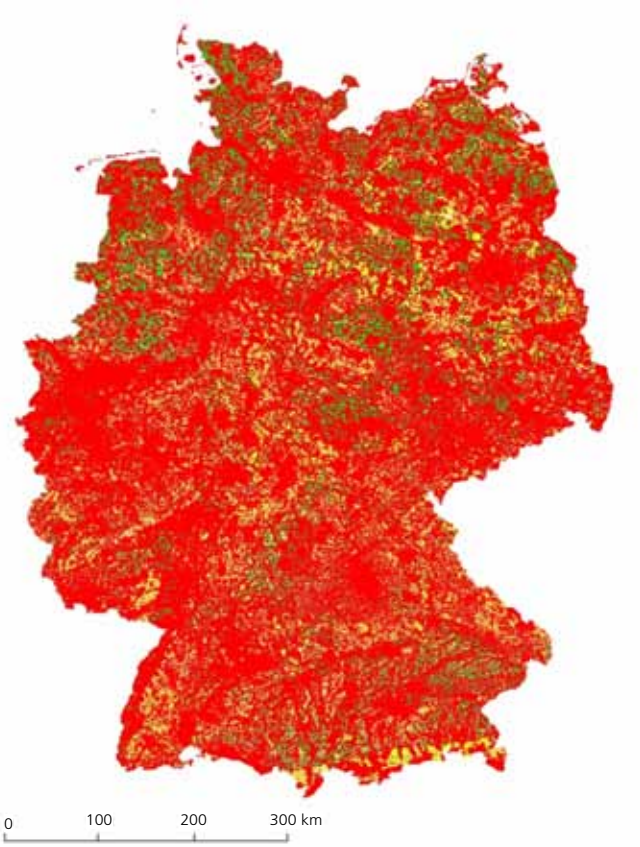
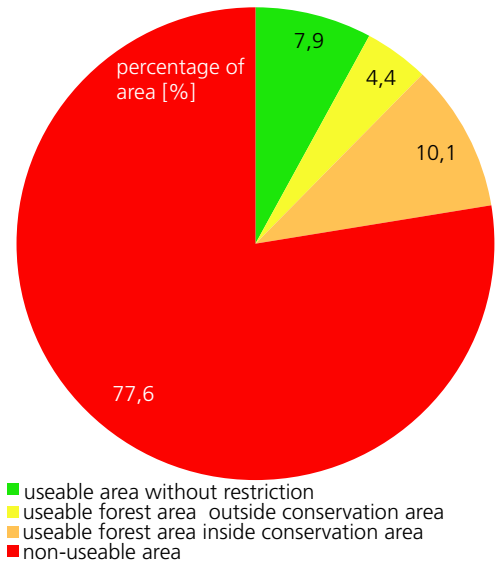


Figure 2: Map showing viable areas for wind turbines in Germany



Other areas such as national parks, urban areas, and surface waters, including relevant buffer zones, were not considered as useable areas.

Calculation of the energy yield

The electricty that could be generated at suitable locations was modeled with a 3 MW wind turbine having a hub height of 100 m and a ratio of rotor surface to generator nominal power of 2.6 m^2 / kW (100 m rotor diameter). If this resulted in an equivalent number of hours operating at full load of less than 1600, the modeling was undertaken with a wind turbine for poor wind conditions (hub height of 150 m and a rotor to generator ratio of 3.5 m^2 / kW; 115 m rotor diameter). If the resulting equivalent number of hours operating at full load was still less than 1600, then this location was excluded from use.

The distance between the wind turbines was set at 4 rotor diameters. Despite this minimum distance, there are aerodynamic losses in wind farms and losses due to technical non-availability. For these, a fixed deduction was taken into account.

Results

Useable areas

The useable areas were split into four categories as per the aforementioned definitions (see Figure 2): Areas without restrictions (green), useable forest areas outside conservation areas (yellow), useable forest areas inside conservation areas (orange), and non-useable areas (red).

Figure 3: Viable areas as a percentage of the total area

More than three-quarters of the land area in Germany cannot be used (see Figure 3). The remaining 22% can potentially be used. About a third of this (8% of the total area) can be used without restrictions (namely it is not in forests and not in nature conservation areas). The useable forest area which lies outside nature conservation areas represents 4% of the total surface of Germany and is hence of interest for wind energy yield.

As expected, the majority of the useable area is in the large German states. The area without restrictions is much reduced in the southern states of Baden-Württemberg, Bavaria, the Rhineland-Palatinate, and Hesse due to the large forested areas (inside and outside conservation areas). Thus the use of forested areas for wind energy utilization is especially relevant here. The areas in the city states are so small compared to the large states that they are hardly visible in Figure 4.

Regarding the states with most useable area (see Figure 5), Saxony-Anhalt (30%) is just ahead of Lower Saxony (27%).

Evaluation of the calculated useable areas

It is assumed that not all the areas designated as theoretically useable will actually be able to be used. Many other aspects play a role (e. g. issues of ownership, army radar).

The aim was, however, to assess the plausibility of the assumptions of the commissioning party. The numbers below hence assume 2% usage of the land for wind energy utilization.

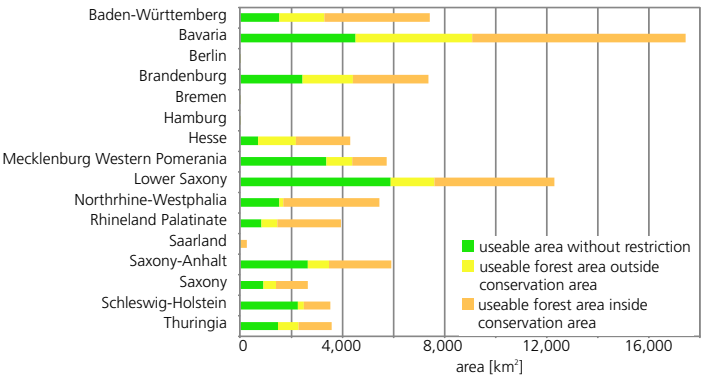


Figure 4: Viable areas in km² in the different German states

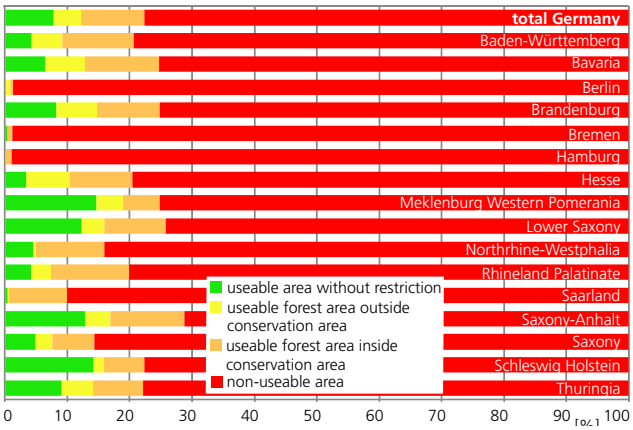


Figure 5: Viable areas as a percentage of the areas of the states

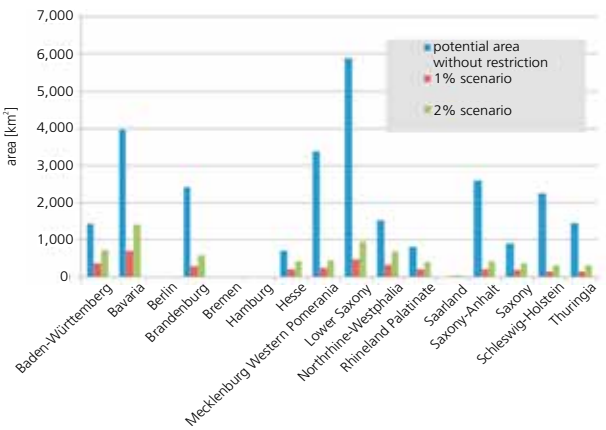


Figure 6: Viable areas (in km²) in the different German states for different scenarios

Wind turbines and generated wind energy

The results presented here give a general picture of the maximum wind power generation capability and should not be deemed to represent a goal. Under the given assumptions, the areas without restrictions (8%, 28,116 km²) are suitable for 240,562 wind turbines having a total nominal power of about 722 GW (or 1500 GW for usage of all potential areas (22.4%)). The total wind power generating capacity installed in Germany at present is 156 GW [BDEW 2011].

The 2% scenario gives power generation capacity of 198 GW. The electricity generation can be estimated to be ca. 400 TWh per year. This corresponds to ca. 65% of the total electricity consumption of Germany (603 TWh) in 2010 [BMWI 2011].

Summary

The Fraunhofer IWES has determined the potential area for wind energy utilization in Germany using GIS data.

The key results are as follows:

- Overall, the 2% goal can be deemed to be realistic
- Based on the GIS data, about 8% of the land area is available for wind energy utilization outside forested areas and conservation areas
- If forested areas and conservation areas are included, the useable area increases to 12.3% and 22.4% respectively
- Usage of 2% of the area of each state corresponds to a total nominal wind power generating capacity of 198 GW
- Viable areas are available throughout Germany and are not limited to the northern states, which are currently most used for wind energy utilization
- The wind energy output ranges from 1600 hours at full load (locations with low energy yield were excluded) to 4996, with an average of 2071 hours at full load
- This gives a potential wind energy output of 390 TWh
- This corresponds to 65% of the total electricity consumption of Germany (603 TWh) in 2010

Literature

[BDEW 2011]
BDEW Bundesverband der Energie- und Wasserwirtschaft e.V., website, Net power generation of power stations in Germany, Status: September 2010,
URL: http://www.bdew.de/internet.nsf/id/DE_Energiedaten

[BKG 2003]
Federal Agency for Cartography and Geodesy, Digital Landscape Model 1:25000 DLM250, Frankfurt am Main, 19.09.2003

[CORINE] CORINE data,
http://www.umweltbundesamt.at/umwelt/raumordnung/flaechennutzung/corine/, visited on 22.3.2011

[DWD]
German Meteorological Agency, Wulf-Peter Gerth, Wind data for Germany, 1981 – 2000, Offenbach

[dena 2005]
Deutschen Energie-Agentur GmbH (dena), Energy planning for the grid integration of onshore and offshore wind energy in Germany up to 2020, Cologne, 24.02.2005

[dena 2010]
Deutschen Energie-Agentur GmbH (dena), dena grid study II. Integration of renewable energies into the German electricity supply, 2015 – 2020 with outlook to 2025, Berlin, 11.2010

[Riso 1990]
European Wind Atlas, Riso National Laboratory, Roskilde, Denmark, 1990

WIND ENERGY REPORT GERMANY 2011

SPECIAL REPORT

Direct Drives and drive-train development trends

Written by Dr.-Ing. Jan Wenske – jan.wenske@iwes.fraunhofer.de

Wind energy business is currently in a phase of diversification concerning drive train concepts. Not only the number of manufacturers has increased, but the number of wind turbine drive-train concepts has increased as well.

Apart from Enercon most of the manufacturers used pretty much the same drive train concept in many of their turbines: a distributed drive-train featuring a gearbox with mostly three stages and a fast running induction or doubly-fed induction generator (IG, DFIG).

This situation was changing. Among the top 10 manufacturers 2010 Enercon and Goldwind have been following direct drive concepts for several years and others like Vestas, GE, Siemens, United Power, Gamesa have already produced or announced producing turbines deviating from the classical drive train concept shortly described above. These days appear all kinds of generator types (IG, DFIG, electrical excited synchronous as well as permanent magnet synchronous generators, EESG, PMSG) in nearly all combinations with drive train transmission ratios, from direct drive up to the high step-up solutions. The highest attention is currently paid to modern gearless designs (Direct Drives, DD; refer to figure 1) featuring single bearing and PMSG.

Constraints and driver for future trends

Components Supply Chain

In the beginning and the middle of the past decade there was a shortage in several key components. Accordingly in 2008, compared to 2006, there was already an oversupply in gearboxes, whereas the shortage in cast iron and forged items was nearly non-existent anymore. Bearings were the last key component with a significant shortage in 2008.

The trend to expand production capacities in wind turbine key components continued to date leading to a tremendous overcapacity, local content requirements and the market entry of new turbine manufacturer especially from Asia since the last 3 years intensify this trend. Regarding generators for direct drive should be noted, that so far no real cost-effective volume production is available.

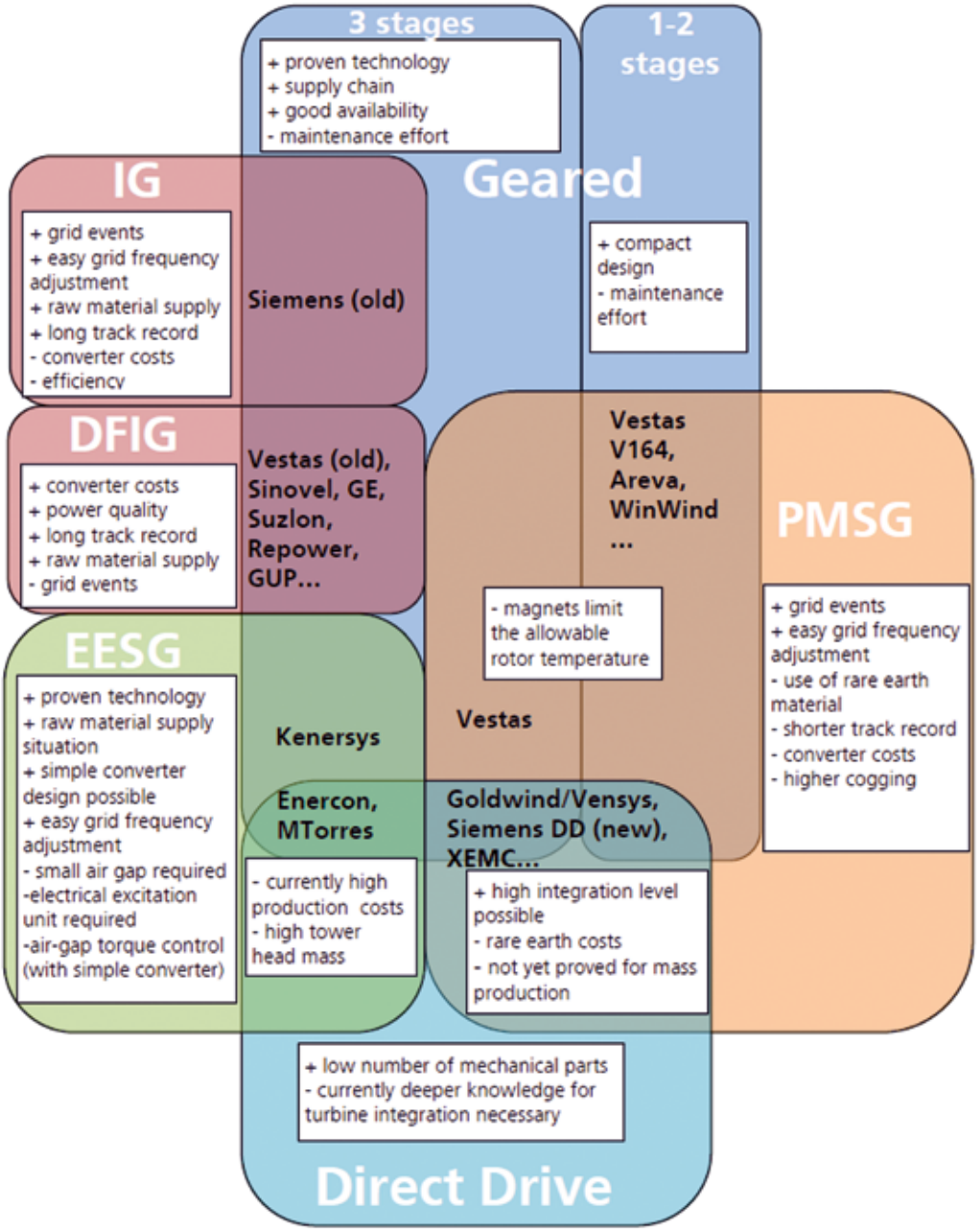
Manufacturer	Country	rotor diameter [m]	rated power [MW]	generator type
Enercon	D	126	6 (7.5)	EESG
		112	4.5	
		101	2/2.3/3	
		82	2/2.3	
		70-71	1.8/2/2.3	
Vensys/Goldwind	CHN/D	70	1.5	PMSG
		100	2.5	
		-	6*	
Siemens	DK	120	6	PMSG
		113	2.3	
		101	3	
Leitwind	I	101	3	PMSG
		70	2	
		80	1.8	
GE	USA	113	4.1	PMSG
Lagerwey	NL	90	2.5	PMSG
EWT	NL	90	2	PMSG
MTorres	SP	-	2.5	EESG
		-	1.65	
Nordex	D	150	6*	PMSG
Alstom	F	150	6*	PMSG
XEMC Darwind	CHN	115	5	PMSG
AVANTIS/Hyundai	KOR	-	2.5	PMSG

** turbine type introduced or announced, but still no prototype*

Figure 1: Direct Drive turbines with more than 1.5 MW of rated power

list of abbreviations

IG	induction generator
DFIG	doubly-fed induction generator
EESG	electrical excited synchronous generator
PMSG	permanent magnet synchronous generators
DD	direct drive
PM	permanent magnet
HTS	high-temperature superconductor



(+ marks "drivers", - marks "constrains")

Figure 2: Drive train concepts with a pros and cons overview

Availability of raw materials and costs. Raw material price development has been proven to be highly volatile in the past. Since different raw materials are used in different concepts in various extents the development of the prices of certain raw materials is important for success of certain concepts. The amount of other raw materials varies significantly depending on the drive train design.

All generators need copper, however DD EESG turbines need the largest amount of copper. Consequently the prices of Enercon's and MTorres' turbines do, to a certain extent, depend on the copper price. The copper price has increased by 28% in the past year. However the copper price in the beginning of 2010 was relatively low and despite massive ups and downs copper prices have not increased significantly compared to the level from five years ago.

Neodymium and Dysprosium are key raw materials of the high performance magnets (NdFeB magnets) used in PMSGs and were subject to intense discussions recently, regarding pricing and environmental effects. In 2011 the price for 1 kg of raw neodymium (/Dysprosium) started with 36 euros (/243 euros), reached a top level of 195 euros (/1,700 euros) in July and fell back to 110 euros (/975 euros) end of this year. The slightly falling price trend continues, albeit at a historically very high level. At the moment 95% of the neodymium is produced in China.

Reliability. Reliability of wind turbines is an important issue, especially for offshore applications.

The to date newest ReliaWind study identified gearboxes to account for only 5% of the failures and downtime and stated a roughly three times higher value for downtime and failure rate caused by the main converters. But on the other hand gearbox failures often involve the systemic risk of prolonged downtime especially in offshore applications and gearing concepts require a periodic and relatively frequent maintenance in comparison to gearless drive trains.

Efficiency. Generalized, high speed (98.5%/97.5%) and medium speed (97%/96.5%) PMSGs/EESGs have a higher efficiency than low speed (95.5%) PMSGs and (92%) EESGs, due to design constraints, like material usage, mechanical dimensions, air gap dimensions plus cooling effort which at the end represent overall costs and turbine weight. However the main advantage of the direct drive concept at this point whether using PMSG or EESG is minimizing losses within the mechanical part of the drive train. On the other hand gearing turbines in actual designs, especially in those concepts using DFIG with less installed power for the converter parts (appr. 50–70% savings compared to a full converter design e.g. for PMSG application) show slightly higher efficiency values for the whole conversion of mechanical into electrical energy (Generator + Converter + Grid connection) in their optimal operating points. Consequently a clear statement concerning the overall efficiency of the different wind turbine drive train concepts cannot be made easily. At last, it should be the annual yield for a given wind distribution at the site instead of the efficiency at the nominal operating point that used as a benchmark. Furthermore, for a comparative study of different concepts all system inherent ancillary units should be taken into account.

Weight and dimensions. Onshore transportation has its constraints. For example motorway bridges in Germany have a height of four meters. Therefore the weight and size of turbines built onshore is an important factor. The weight and size issue connected with various turbine concepts has been discussed a lot in the past. However, it can be stated, that the modern DD turbine developments (e.g, by Siemens) are very close to the latest benchmark geared turbines (e.g. Vestas V90-3.0) in respect to their specific nacelle weight.

Grid Compatibility. One aspect gaining importance with the increasing utilization of wind energy is the "quality" of the power fed into the grid and the wind turbines reaction to grid events.

Turbines using full converters have better capabilities in handling grid events than DFIG turbines intrinsically. However, the power delivered by the geared DFIG solution is of good quality, even more sophisticated control effort and hardware protection systems are necessary to comply with most of the to date grid codes. The biggest limitations with DFIG technology reveal by the lack of a complete decoupling between the mechanical and electrical system performance.

Conclusion (drive train trends 2015)

The conclusion, due to the great differences between on- and offshore business, can't be uniform, but some trends become quite evident.

Onshore. The onshore wind energy business can be regarded as a relatively mature business. Components applied in medium sized onshore wind turbines, i. e. 1 MW – 2.5 MW are de facto standardized; the turbine production has turned into mass production with moving production lines already used by several manufacturers. The cost-sensitivity of onshore turbines will grow continuously. For the near future IWES expect, the average size of onshore turbines will be limited to approx. 3 MW.

The dominating concept for onshore wind turbines in the past decade, despite the above mentioned drawbacks, was the gearing DFIG design. But PMSG solutions have some advantages not to be neglected. The main advantages are the inherent slightly greater efficiency of the generator and their better grid compatibility. Obviously, DD turbines have a greater efficiency within the mechanical drive train than gearing concepts. The advantages of gearing PMSG over DD PMSG turbines are the lower demand on permanent magnet material as well as their 2–3% higher generator efficiency. At the moment the investment costs for PMSG systems, especially for DD concepts, are higher than for DFIG systems. Even though PMSG machines will become cheaper in the future due to increasing production numbers and a higher automation level, these effects will probably not outweigh the cost advantage of DFIG systems.

This leads to the assumption that different turbine concepts might be interesting for different markets due to different countries rely on different incentive mechanisms to foster the use of wind energy.

Offshore. The requirements for offshore application differ from the requirements for onshore turbines due to the different cost structure. Costs for service and maintenance are significantly higher than onshore. Failures can lead to extensive downtimes and thereafter cause high production losses. Consequently high reliability and sophisticated service concepts are inevitable.

Due to this fact DD PMG turbines seem to have at least a psychological advantage, but still holding only a short track record. Gearbox failures seem to be still an issue and unreliable electrical systems could become a massive problem for offshore applications. Most of the recently developed and announced offshore wind turbines, for example from Siemens, XEMC Darwind, Nordex, Alstom, are DD PMSG turbines. Some players like Sinovel, Repower and Bard favor geared concepts with DFIGs.

Other big players like Vestas and Gamesa have developed or are currently developing geared offshore turbines with a medium speed PMSG. Nonetheless a current trend toward DD PMSG for offshore turbines becomes apparent. At least in medium term the market share of gearless turbines will exceed that of those with gearing drive-train concepts.

Finally trial for a technical foresight (>2020) on offshore drive train applications

- For weight limiting of the DD generators despite of turbines power output up to 10 MW, the currently force densities within PM-Generators of approximately 60–70 kN/m² will increased to 90–100 kN/m². This will be solved by better cooling and rotor designs with magnetic flux concentration. In contrast the energy density and remanence field strengths of the used permanent magnetic material will increase only modestly (< 10%). Driven by serial production cost reduc-

tion, tooth-coil-winding stator designs will be featured additionally to the classical distributed stator winding.

- Due to the continue of rather high prices for high performance PM-material new 4–6 MW turbines with electrically excited DD generators will enter the offshore market. The design lowers the risk for unexpected production costs and avoids potential bottlenecks for PM-material. The systemic efficiency disadvantage relative to PM generators will be almost leveled by intelligent mechanical designs with a small, stabilized air gap in the range of 3–4 mm. The advantage of the adjustable excitation will be actively used to maximize efficiency at partial load.

- For some turbines featuring medium-speed generators also EESG and DFIG designs beside the PMSG will be used. Additionally first innovative hybrid designs for generators, with electrical and magnetic excitation as well as featuring reluctance effects, will appear within prototypes. These will combine the advantages of high power density and the low-loss control of the excitation field together.

- Transverse flux and HTS – generator designs have no relevance in the market for wind turbines until 2050.

- The drive train designs will evolve towards the highest integration and simplicity. The current trend towards ever larger single bearings will be replaced by a main support design with smaller bearings and a well defined load sharing. The figure 3 exemplary shows the concept of an innovative DD hub generator design with dual bearing support and with the main goal of minimizing manufacturing and maintenance costs as well as the overall nacelle weight. (refer to figure 3 DD offshore hub generator design of the FGWE/ Saarland and IWES)

Figure 3: Ultra high integrated hub-generator DD design

WIND ENERGY REPORT GERMANY 2011

SPECIAL REPORT

New Techniques for Wind Measurement at Fraunhofer IWES

Written by M.Sc. Tobias Klaas – tobias.klaas@iwes.fraunhofer.de

Wind lidar measurements

The Fraunhofer Institute for Wind Energy and Energy System Technology (IWES) runs a manifold measurement infrastructure for the investigation of wind characteristics at onshore and offshore sites in Germany. Lidar systems, as a remote sensing technique, become more important and are a main topic of the current research.

The pulse-doppler lidar systems used at the Fraunhofer IWES, are applied to measure the vertical wind profile in a contactless way (remote sensing) up to great heights and over the whole rotor diameter.

The measurement is based on the optical Doppler effect: The frequency of a radiation respectively its wave length is changed in as a function of the relative movement of source and receiver against each other. This principle is valid for acoustic as well as for electromagnetic waves.

The wind noticeable to us is based on the collective movements of molecules and aerosols in the atmosphere. The basic idea of a lidar wind measurement is to send out laser light waves to these components of the atmosphere. The reflected radiation can be detected and analyzed with respect to a frequency shift.

FIELDS OF APPLICATION

Onshore – Wind power onshore has still a huge potential for further growth. To assess this potential, especially in forested and complex terrain, a detailed knowledge about the wind conditions up to higher altitudes is important. With current tower technologies allowing the installation of turbines with hub heights up to 150 m, extrapolation methods for traditional mast based measurements at low heights are becoming increasingly unreliable – particularly under consideration of today's large rotor diameters. tobias.klaas@iwes.fraunhofer.de

Offshore – In the field of offshore wind energy the use of lidar systems on floating platforms under the influence of wave motion is studied. Different kinds of movements, like rotation, heave and surge distort the measurement procedure and influence the obtained wind speeds and directions. Methods for the correction of the falsified data are developed and verified using simulations as well as well defined experiments, where wave motion is simulated and the result compared with a met mast. gerrit.wolken-moehlmann@iwes.fraunhofer.de

Ground based remote sensing using lidar technique is a new option to complement or eventually replace mast mounted measurements. Lidar measurements have shown a high accuracy in even, homogeneous terrain i.e. offshore or in flat lands. In contrast, applying these techniques in hilly or mountainous terrain, results in considerable bias. The reason for that is the assumption of homogeneous wind flow on distinct heights due to the principle of the 3D wind vector reconstruction, which is not sufficiently fulfilled in complex terrain.

In a lidar wind measurement the radial wind components in direction of the laser (line-of-sight) are being determined in at least three spatial directions. To calculate the wind vector from these radial components it is usually assumed that the wind field between the different measurement points is (horizontally) homogeneous. Measurements in flow fields that do not meet these assumptions are biased.

The determination of the wind speed with lidar measurement devices equals the calculation of a vectorial mean. Firstly the radial components are being determined at different location, which equals calculating the mean for each vector component. From these components the mean wind speed is being constructed as a vectorial mean.

The measurement of the radial vector components is carried out at different measurement points above the measurement device, depending on measurement height and cone angle. The measurement geometry usually follows the velocity azimuth display principle (VAD). Azimuth and measurement height

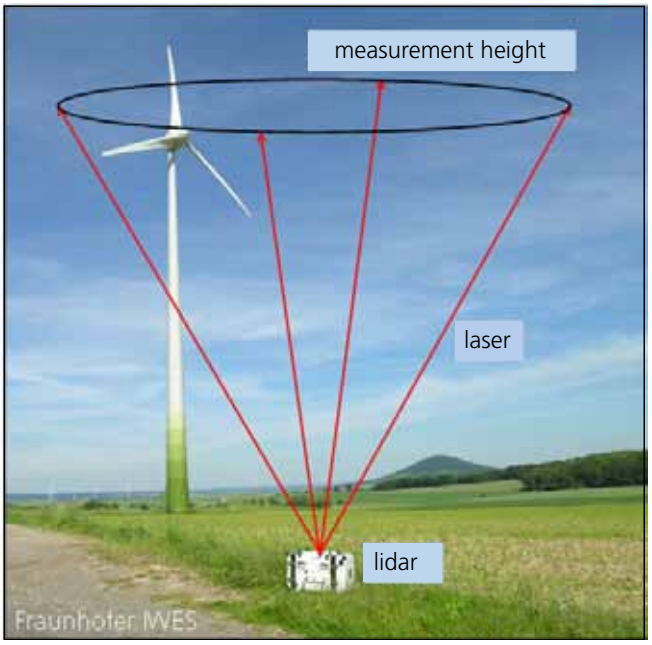


Figure 1: Lidar wind measurement system

can be varied, while the angle of inclination is fixed. With this determination it is not possible to accurately measure the wind speed in inhomogeneous wind fields.

As soon as the z-component of the wind speed is a function of the x- or y-coordinates, measurement bias occurs in comparison to a point measurement by cup anemometers. This bias can be corrected by different methods.

For the correction of lidar wind measurements in complex terrain flow models are more and more used. Depending on the complexity of the terrain a reliable correction is only possible with complex flow models. One main reason for this is that the classic boundary layer theory is no longer applicable in complex terrain. Failures in simple flow simulations (e. g. WAsP) are the consequence.

With a flow simulation of a complex site the lidar wind measurement as well as the common point measurement can be simulated. Both measurements can be compared to each other and methods for correction can be developed. As an example it is possible to characterize the change of the vertical wind speed between the different measurement points and to correct the lidar measurement in this manner.

Figure 5 illustrates the influence of the change of the vertical wind speed at the accuracy of a lidar wind measurement. The grey points equal the measurement points for the radial wind speed components at 100 m height with a laser inclination angle of 30°.

The wind field has been simulated for the site of the 200 m wind met mast, which is located near the top of a hill range. The hill flow at west wind conditions is clearly shown. The strong deviation in the z-component of wind speed between the southern and the northern measurement point results in a high measurement failure in wind speed.

200 m wind meteorological mast

The use of lidar as a novel and advanced measurement technique puts special emphasis on the new 200 m high quality reference mast that is used to validate and develop those measurements in detail.

Particularly with regard to system immanent failures of lidar measurements in complex and mountainous terrain, the 200 m met mast enables Fraunhofer IWES to develop and evaluate advanced correction algorithms for future onshore applications.

Figure 2 shows a schematic illustration of the wind met mast. The mast is designed as a steel framework with a cross-section area of only one square meter. Along its height of 200 m it is guyed with steel cables in four directions at a total of ten heights.

With this building the Fraunhofer IWES owns a worldwide unique measurement system for the exploration of wind characteristics in forested, complex inland terrain, especially qualified for research topics in the field of wind energy.

The measurement site is located at the ridge of a hill at a potential wind energy site in a low mountain range in northern Hesse. Within the current project research activities in wind characteristics, lidar measurements, load measurements and wind energy potential are planned.

The mast is equipped with cup and 3D ultra sonic anemometers as well as multiple wind vanes. Additionally pressure, temperature, temperature difference, humidity, rainfall and global radiation measurements give access to current weather and atmospheric conditions.

With a vertical distance at the utmost of 20 m wind speed sensors are installed all in all at 13 heights, resulting in a highly detailed wind profile measurement up to great heights. Measured wind profiles can therefore be evaluated and analyzed in a very detailed way. In addition to the 10 minute mean values and the measured 1 Hz data, the installed ultra sonic anemometers are recording 3D wind data at a high frequency of 50 Hz. Based on these data, detailed examinations of the 3D turbulence of the wind can be carried out.

Figure 4 shows first measurement results of a measurement campaign around Christmas 2011. For this campaign one lidar system was set up next to the measurement mast. During the time of the measurement no anemometers above 100 m apart from the top anemometer on 200 m were available. Lidar measurement data has been recorded for heights up to 220 m. The results show that the lidar measurement failure is relatively low for this site during the measurement time. The roughness parameter of the log law fit is slightly higher for the mast. At data points where lidar and mast can be directly compared, the mean values for the profile are slightly higher for the mast. This means the lidar tends to underestimate the wind speed.

For a detailed analysis of the measurement failures more data is needed. Wind speeds during the above shown measurement campaign were mostly quiet high with wind coming only from a narrow direction sector. After a longer measurement campaign more data will be available to compare lidar and mast measured

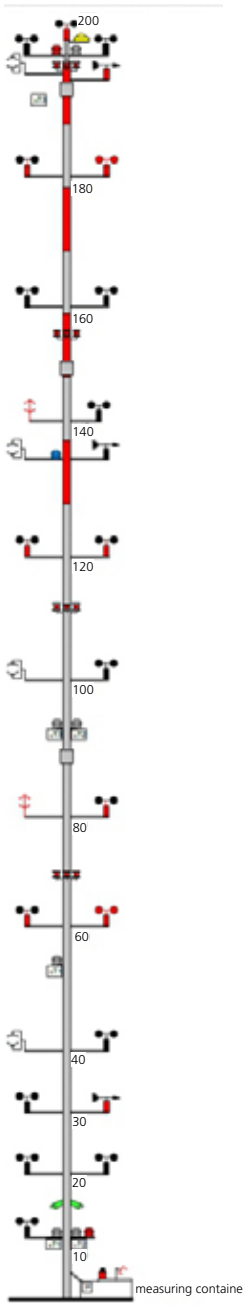


Figure 2: 200 m wind met mast

Figure 3: Construction of the 200 m wind met mast

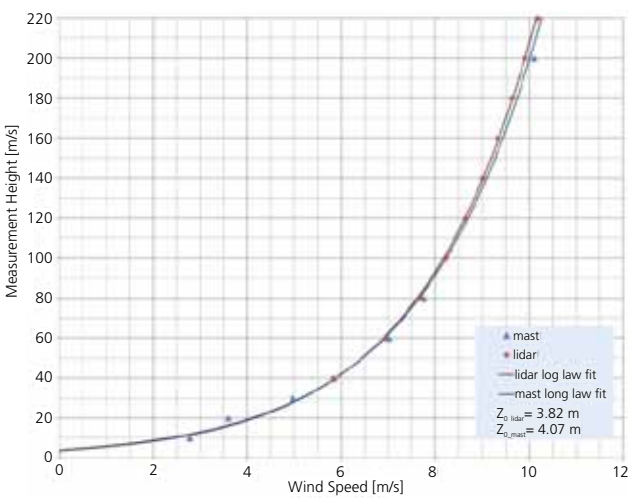


Figure 4: First measurement results lidar and mast. Short measurement campaign around Christmas 2011

wind speeds in dependence of direction, daytime and weather conditions more detailed.

Conclusion

The 200 m wind met mast is a valuable tool for both: The evaluation of flow models for complex and forested terrain as well as the testing and development of state-of-the-art correction algorithms for lidar wind measurements in inhomogeneous wind fields.

A comparison of the wind measurements with the data of the 200 m wind met mast forms a beneficial basis for increasing the accuracy of the measurements in complex terrain and the development of reliable correction algorithms for lidar wind measurements.

As a first approach the actual measurement failures of the lidar are being evaluated in a comparison to the mast based point measurements. The wind profile can be analyzed as a function of wind speed and wind direction. With the parallel measurement of the most important atmospheric parameters a classification of the wind profiles into different atmospheric stabilities is possible. With sufficient measurement time scientific findings can be made about the influence of measurement height, wind speed and atmospheric stability at the measurement. All the effects can therefore be considered during the development of accurate correction algorithms.

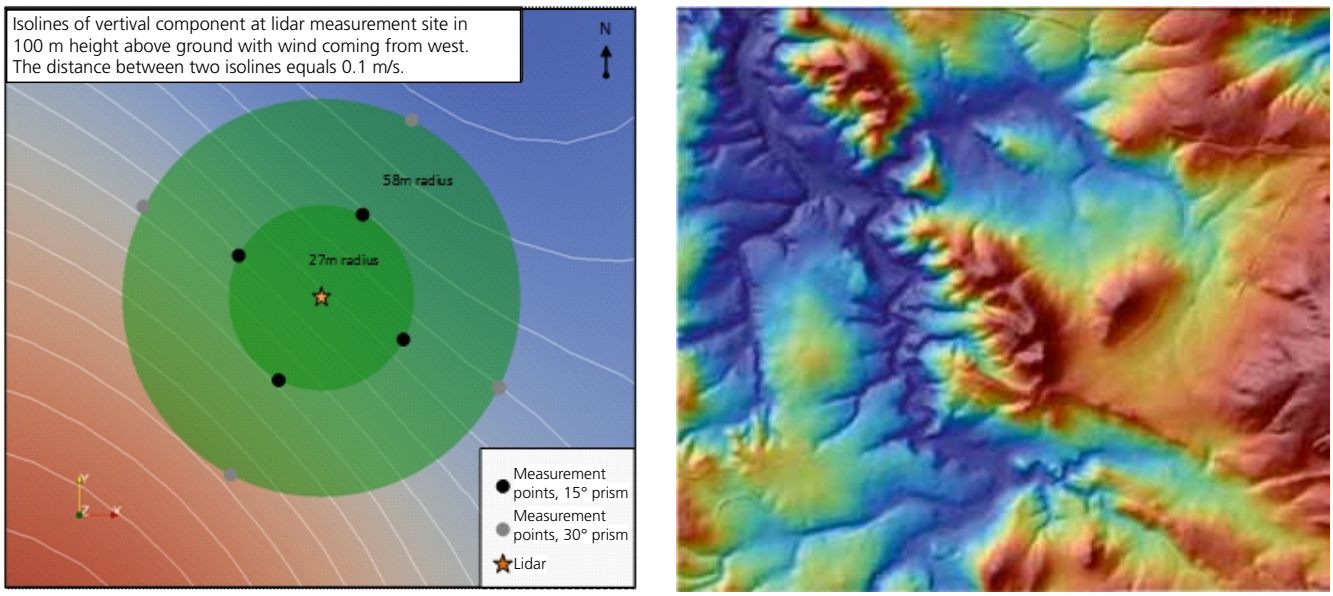


Figure 5: Left: Isolines at vertical wind component at a lidar measurement site (simulation), Right: Shaded relief of the measurement site with hill range in the middle

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SPECIAL REPORT

ORECCA – Offshore Renewable Energy Conversion Platforms Coordination Action

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Project objectives

ORECCA is a Coordination and Support Activity type project which started in March 2010 funded under the Seventh Framework Programme (FP7) by the European Commission Directorate-General (EC DG) Research. The project stimulates collaboration in research activities leading towards innovative, cost efficient and environmentally friendly offshore renewable energy (ORE) conversion platforms for wind, wave and other ocean energy resources, including their combined use. This is being achieved through the development of a first European road map for the entire marine renewable energy sector. The project therefore focussed on establishing the state of research, technological development and demonstration activities on offshore renewable energy conversion platforms and on the definition of strategic priorities, including socio economics aspects, for the development of offshore renewable energy conversion technologies and markets. Another objective of the project was to overcome the knowledge fragmentation existing in Europe and stimulate the key experts to provide useful inputs to industries, research organizations and policy makers on the necessary next steps to foster the development of the ocean energy sector in a sustainable and environmentally friendly way. This is achieved through the creation of a framework for knowledge sharing (www.ORECCA.eu).

Resources

The three geographical target areas are the North & Baltic Sea, Atlantic and Mediterranean & Black Sea. Potential building plots have been identified based on the amount and type of renewable energy resource available and on the sea characteristics together with consideration of the offshore and onshore infrastructure (Figure 1).

All in all about 70% of all offshore renewable energy resources can be found in water depths of more than 50 m (Figure 2), the "hot spots" for energy harnessing being identified as the western facing Atlantic coastline (UK, Ireland, Spain and Portugal) and the nothern North Sea (Norway, UK).

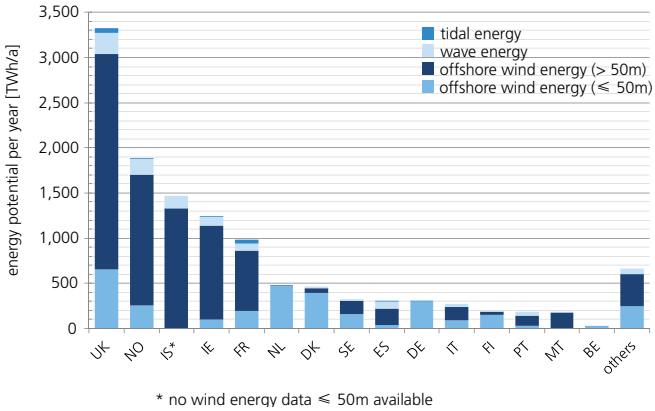


Figure 1: Potential of offshore renewable energy resources of selcted European countries

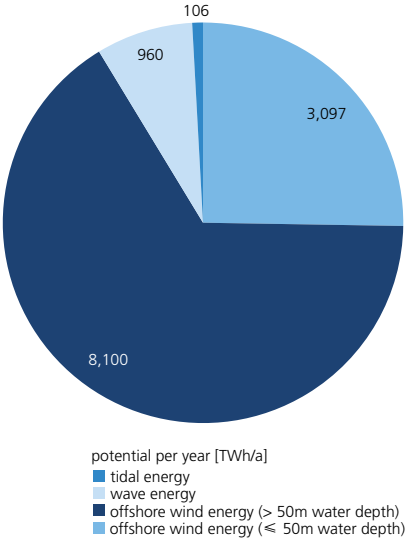


Figure 2: Share of offshore renewable energy resources in European waters

Installation schedule

Offshore wind energy and ocean energy in North-, Baltic- and Mediterranean Sea and the European Atlantic regions together could technically provide all of Europe's future electricity demand. Around 3.8 GW of offshore wind turbines are already installed throughout Europe (end 2011); the water depth and distance to shore of offshore wind farms locations rose from under 20 m and 20 km to 40 m and 40 km (Figure 3). These numbers will increase further in the coming years, considering the huge distances of the projects in the German EEZ and the

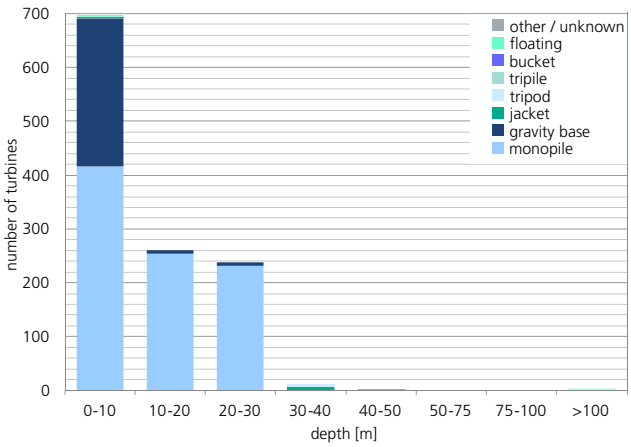


Figure 3: Foundation types of wind turbines in fully functional offshore wind farms in certain water depths [IWES, 4COffshore 2012]

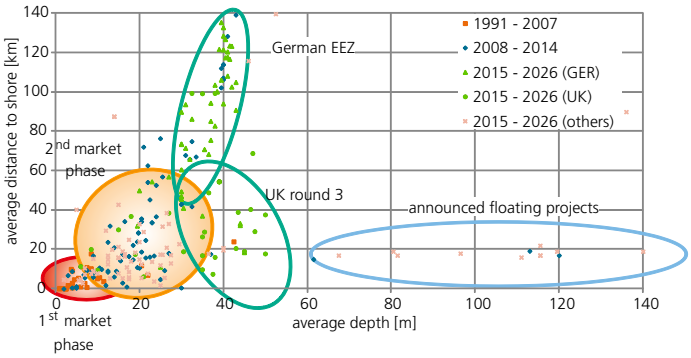


Figure 4: Development of the offshore wind market in terms of water depth and distance to shore up to 2026 [IWES, 4COffshore 2012]

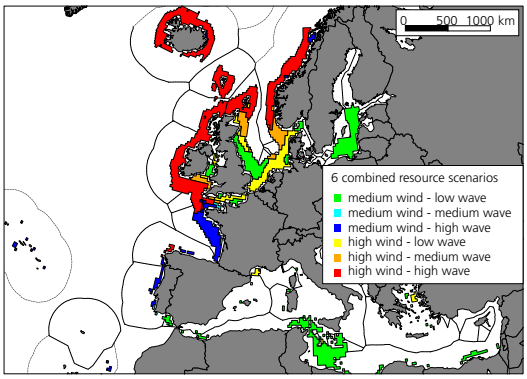


Figure 5: Identified areas of combined wind- and wave resources in Europe [RSE]

water depths of the announced floating wind projects in the North- and Mediterranean Sea (Figure 4).

Investigations during the project lead to the observation that the utilization of ocean energy follows about ten years behind that of offshore wind energy regarding immatureness of technology and realized projects. In addition, the current installation pipeline of offshore wind capacity exceeds current projections by 100% in 2020 (Figure 6), while the installation pipeline of ocean energies currently falls below the 2020 targets by 50% (Figure 7).

Combined resources

Considering these numbers, facts and projections the project proposes the colocation of wave- and wind projects in order to benefit from a shared infrastructure (electrical grid, port facilities, installation- and service vessels) as the utilization of combined conversion platforms is immature. A number of adequate areas have been identified and classified with respect to the intensity of present wave- and wind resources (Figure 5).

This map amongst many others (bathymetry, wind speeds, wave energy, wind-, wave- and tidal projects locations...) can be accessed via the webGIS application, integrated into the ORECCA website.

Roadmap

Distilling the results from nine extensive technical reports covering the aspects of investments & grants, environment, resources, site selection, design tools & standards, state of the art platform technologies, synergies, offshore grids and installation infrastructure into one roadmap, the ORECCA project proposes the following steps and measures to boost the development of ORE conversion technologies and markets:

- While offering huge resources ORE are currently not competitive without market incentives. Funding and public support is generally well established and appropriate. But in only 4 out of 12 countries investigated the production based incentives (PBI) are significantly higher for wave and tidal – than for

offshore wind energy. In order to accelerate the use of the untapped ocean energy resources it is proposed to enhance and extend capital support, incentives and funding for ORE.

- Regarding the technology it is required to focus on cross-technological standardization of components and procedures, enhance collaboration as well as knowledge transfer from neighbouring industry sectors and gather more performance data and operating experience in the field.

- The requirements towards installation infrastructure such as ports and vessels have to be further investigated with respect to the needs of the offshore wind- and ocean energy industry, in particular when considering increased water depths and distances to the coast of future projects at the resource hot spots identified. The development should be directed towards the combined respectively shared use of infrastructure. The electrical offshore grid should be extended to a pan-European scale, not neglecting the reinforcement of national grid capacities, especially in Norway, Ireland and the UK.

- On the environmental issues it is proposed to extend research on cumulative effects, EMF effects of subsea cables, flow alteration, sedimentation and habitat change and mitigating actions for piling.

- Furthermore it is proposed to harmonise legislation and regulation on a transnational level, leading to the establishment of streamlined one-stop-shop marine consenting systems, maritime spatial plans and strategic environmental assessment in all relevant countries. Legislation and regulation should evolve together with the growth and development of the offshore energy industry and compliance should be ensured by clearly defining and properly communicating these rules and laws.

The full roadmap and the executive summary together with all reports can be accessed via the ORECCA website.
Visit www.ORECCA.eu for further information.

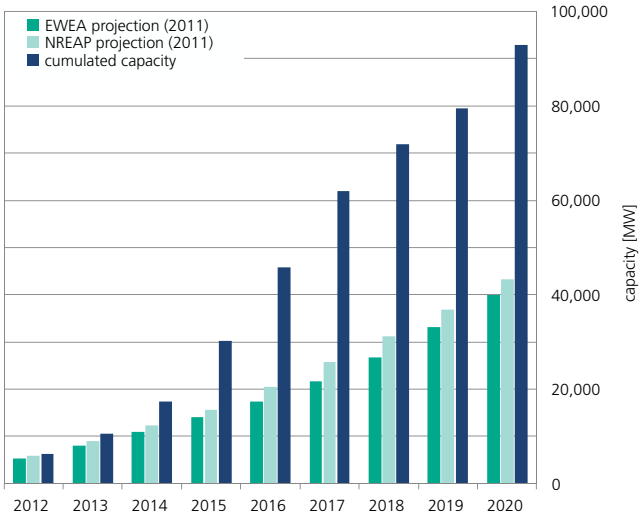


Figure 6: Offshore wind installation projections and schedule of European countries [IWES, 4COffshore, 2012]

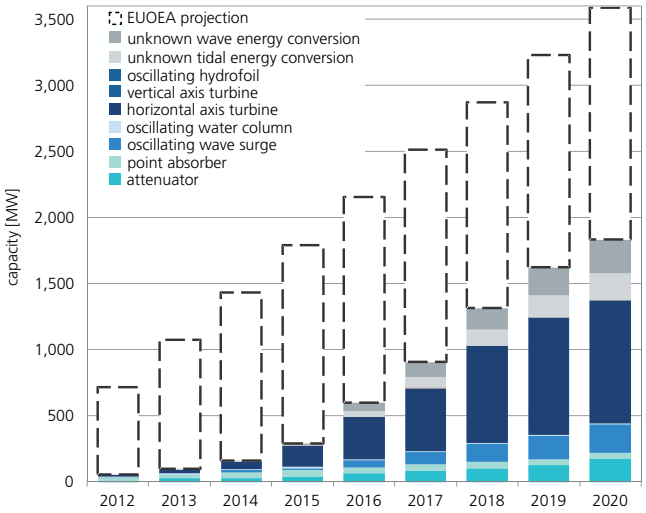


Figure 7: Installation projection and schedule of different wave and tidal conversion technologies in Europe [IWES, 2012]

Bibliography

http://ewea.org/fileadmin/ewea_documents/documents/publications/statistics/EWEA_stats_offshore_2011.pdf
http://www.4coffshore.com/windfarms
http://www.orecca.eu/

WIND ENERGY REPORT GERMANY 2011

SPECIAL REPORT

Support Structures

Written by Dr. rer. nat. Rüdiger Ernst[1]; Dr.-Ing. Holger Huhn[1]; Dr.-Ing. Martin Kohlmeier[1]; Prof. Dr.-Ing. habil. Raimund Rolfes[2]; Prof. Dr.-Ing. Peter Schaumann[2] – 1) Fraunhofer IWES; 2) Leibniz Universität Hannover – ruediger.ernst@iwes.fraunhofer.de

Offshore wind energy

In the new energy concept of the German Federal Government an accelerated development of offshore wind energy was pointed out [1]. Together with an economic OWT operation, the technical reliability plays a distinctly major role compared to onshore wind energy converters (WEC). This is true especially for Germany intending to install a very high share of OWT far away from the shore line. Therefore, the further development in offshore wind energy should be planned carefully and step by step.

2011 was another year with a dynamic growth of installed wind energy power [2, 3]. R&D activities are still playing a major role to ensure this positive trend. In the international context further countries like China have enhanced their activities qualitatively and quantitatively. The global economic competition is growing.

Concerning OWT installation under high sea conditions there are still some disadvantages such as high transport, production and maintenance costs. Moreover, during the offshore work job safety and environmental tolerance (acoustic problems) should be further improved. For important environmental reasons, this is especially true for North Sea wind farm projects in the German Bight, which are to be installed far from the mainland in relatively deep sea regions with a water depth of more than 25 m.

The optimization and development of support structures is one of the main issues to improve the technical availability, reliability and economy of OWT. During the design process, the support structures and foundations have to be adapted to the given offshore site conditions, namely to the geotechnical, meteorological and oceanographic data. The planned technical OWT design also has to be regarded.

Support structures and foundations of OWT

In the international context, OWTs were founded using driven piles as monopile or group of piles generally with a great diameter between 2 m and 4.5 m. Moreover, gravity-based foundations have also been used in case of a capable seabed [2].

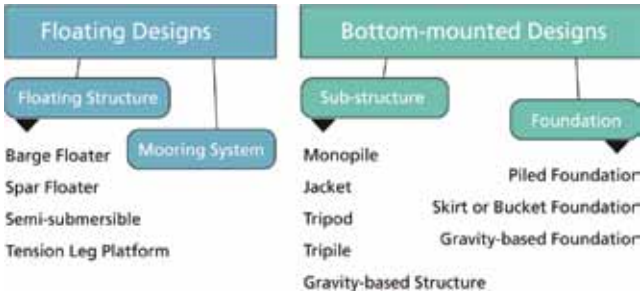


Figure 1: Support structures of Offshore Wind Turbines (OWT)

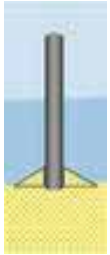
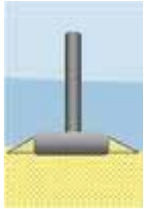
Figure 1 gives an overview of present OWT design and support structures and respective foundations applied. Bottom-mounted structure designs are clearly ruling, using deep (pile mainly) or shallow foundations.

Floating OWT designs are usually applicable for a great water depth. These constructions are moored in the sea ground. These generally promising support structures are under intensified investigation but up to now floating designs have rarely been used.

Bottom-mounted main support structures for OWT are summarized in Table 1, along with some basic structure characteristics, advantages and disadvantages.

Regarding the situation in Germany, a relative small number of OWTs (n <100, until 2011) was installed mainly on driven piles. Monopile, jacket, tripile and tripod structures have been used up to now. Moreover, land-based tests were performed on a gravity-based foundation structure.

Up to now, suction bucket foundations are rare examples worldwide concerning OWT.

Substructures	Basic characteristics	Advantages / Disadvantages
	**Monopile.** cylindric hollow pile, made of steel mainly applicable effectively up to diameter 5-6 m up to max. 20-25 m water depth currently with driven, partly with bored piles load application mainly lateral transition piece to connect the tower	easy transport and installation pile driving with strong sound emission (environmental problem) low cost foundation flexible structure relative low wave intensity is allowed main foundation type today scour protection
	**Gravity Based Structure (GBS).** concrete structure for shallow to medium water depth, pre-fabrication onshore shallow foundation with scour protection needs a stable ground near to surface fabrication in floating docks mainly floating transport or using ships	costs have been reduced now not so depending on steel prices more sensitive to stability and scour, fundament cover often a full base pressure load is needed → weight no pile driving work
	**Jacket.** Skeleton framework made of steel 4 foots are supported/ anchored by pile foundations mainly applicable to greater depth, 25-50 m low structural weigth vertical load application to piles is ruling can be produced onshore	slim structure (steel consumption) easy transport and installation sensitive to clashes has a long application history in Oil & Gas industry a proven construction pile driving with strong sound emission scour protection
	**Tripod.** Skeleton framework made of steel main pipe with 3 steel feet water depth 20-40 m recommended loading variable, compressive and tensile forces supported/anchored by pile foundations can be produced onshore	estimation of acting wave loads is possible empirically and roughly higher material weight smaller piles diameter are possible compared to monopile pile driving with strong sound emission scour protection
	**Tripile.** Skeleton framework made of steel 3 foots are supported/ anchored loading variable, compressive and tensile forces can be produced onshore	estimation of acting wave loads is possible empirically and roughly higher material weight smaller piles diameter are possible compared to monopile pile driving with strong sound emission scour protection
	**Suction bucket (skirt).** open closed steel pipe(s) shallow or deep foundation type under pressure installation of foundation, which is taken sucked up	no pile driving work sometimes tricky installation installation problems are possible, soil (suction) failure observed

Model validation and optimization

Technically safe and economical support structures of offshore wind turbines (OWT) should be obtained using project experiences and an optimized design process with sophisticated, more realistic simulation models and tools. During the structural design process, accompanying experimental tests on scaled support structure models should contribute considerably to the validation of simulation models and tools.

Validation and optimization are among the main goals of research and testing of OWT support and foundation structures. OWT support structures should be constantly better adapted to the specific and demanding offshore site conditions. Among the R&D subjects there is the deformation behavior and capacity of foundation elements such as monopiles, soil-structure-interaction, fatigue, hybrid construction materials, procedures of geotechnical engineering or material protection against corrosion.

Test Center for Support Structures

By 2014 Fraunhofer IWES will start large-scale cyclic and respective dynamic tests on support structures in a new test centre ("Testzentrum Tragstrukturen"). Various designs of OWT structures and single structure components will be tested, applying variable and multi-axial loads to devices under test.

Currently foundation structures of OWEA are in the focus. The investigations are intended to contribute considerably to reliability.

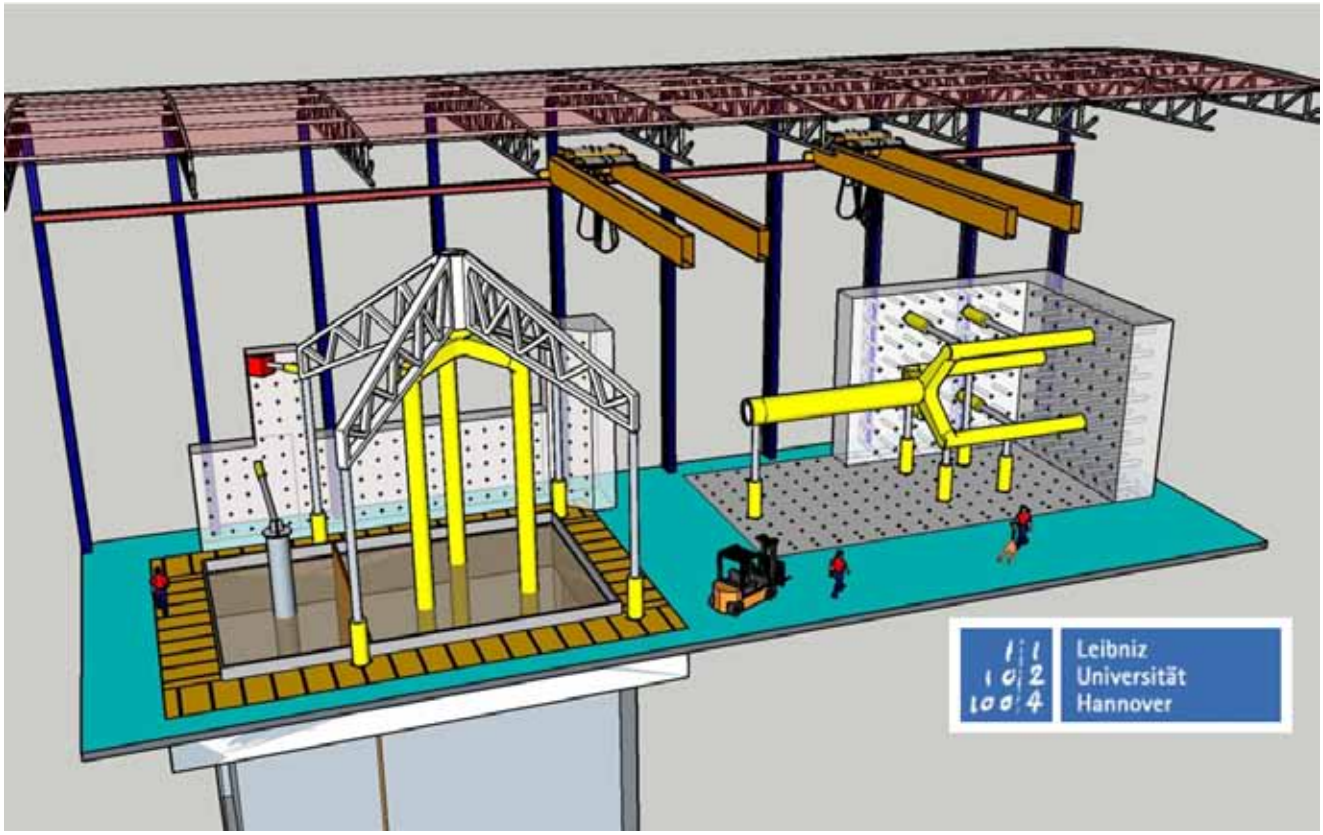


Figure 2: Model of the test hall for support and foundation structures and single structure components with the large-scale test equipment geotechnical test pit and span

Regarding the present level of technical and economical development in the field of wind energy and the main future trends turning energy production from nuclear power to renewables, the construction of a cutting-edge test centre for support structures is a necessary step to use the given offshore wind potential in a safer and more efficient way.

Geotechnical test pit and span

The test center for support structures has been designed as a testing plant for experimental investigations in the field of offshore wind energy turbines on a large scale. Two single large-scale test facilities will be the main pieces of the new test hall – a geotechnical test pit and a span. Using these test facilities, experimental cyclic and respective dynamic tests can be executed, applying multi-axial loads to OWT devices under test. The geotechnical test pit has an outline of rd. 14 m × 9 m and a designed depth of around 10 m. The pit will be filled with sandy material mainly similar to typical sea ground conditions. The sandy filling will be compacted and saturated with water.

Both test facilities have 8 m high reinforced massive concrete abutment walls for introducing horizontal loads.

Test scenario

The objectives of the test centre were developed in collaboration with representatives of the wind energy industry. The main testing objectives can be defined as follows:

- Dynamic tests on large-scale support and foundation structures
- Investigation of structure-soil-interactions on piles and other foundation structures in soils saturated with water, applying lateral and vertical loads to devices under test
- Assessment and optimization of enhanced installation techniques or support structure concepts
- Detailed investigation of structure components (fatigue tests, lifespan prognosis)
- Investigation of hybrid connections and joining techniques.

For example, the load bearing and deformation behavior of a single pile or group of piles of OWT can be tested in the geotechnical test pit, applying variable dynamic loads.

The span can be used for fatigue material tests of structure components, welded joints or hybrid grouted joints; also for construction materials and mechanical joints like large bolts.

Furthermore, tests of the behavior of foundation piles are possible applying a very large number of multi-axial load cycles. Applying lateral and vertical loads, these tests should give detailed information about the long-term behavior of support and respective foundation structure models. The trends of some decisive dynamic soil and material parameters can be investigated and evaluated more precisely.

Using the new, worldwide singular large-scale testing set-up, the experimental investigation possibilities are clearly extended. The test results can be used to answer problems lying beyond the experiences of present OWT operation.

The offshore typical long-term response of structure and substructure can be better investigated under cyclic loads, caused mainly by waves and wind.

Altogether, the designed experimental tests on large-scale structure models or single components are focused on a safer assessment and validation of OWT support structures. This is related to the overall system behaviour, support structure and foundation deformations, material fatigue behavior, operational stability, capacity of pile foundations under long-term cyclic loads, system reliability, lifespan and, last but not least, to more cost effectivness.

Another important aspect of scientific and commercial use of the test centre will be a close cooperation between Fraunhofer IWES and the research network ForWind.

Project group for support structures

Running parallel to the project and design activities of the test center, a new "Project Group for Support Structures" as part of Fraunhofer IWES Bremerhaven is set up in Hannover. The group members are getting permanently more familiar with the subjects of the test centre and the experimental test procedures.

The project group staff are becoming aquainted with aspects of the new test center, hereunder issues of usage and operation, present problems of planning, installation and operation of OWTs, experimental testing and pilot test sets, quality management, measuring methods and data monitoring and numerical calculations with respect to support structure models.

The design of calculation tools for experimental model structures has begun.

References:

[1] www.offshore-wind.de
[2] Wind Energy Report Germany 2010, Fraunhofer Institut für Windenergie und Energiesystemtechnik IWES, Kassel und Bremerhaven
[3] www.bwe.de
[4] Lesny, K.: Gründung von Offshore-Windenergieanlagen – Werkzeuge für Planung und Bemessung – Mitteilungen aus dem Fachgebiet Grundbau und Bodenmechanik 36, Universität Duisburg-Essen, 2008
[5] Randolph, M.; Gourvenec, S.: Offshore Geotechnical Engineering.- Spon Press, Abington, 2011
[6] Dean, E. T. R. Offshore geotechnical engineering – Principles and practice – Thomas Telford Ltd., London 2010
[7] www.gigawind.de

WIND ENERGY REPORT GERMANY 2011

LITERATURE

[1] 10-Jahres Plan von ENTSO-E, https://www.entsoe.eu/index.php?id=282

[2] Andor M., Flinkerbusch K. et al (2010) Negative Strompreise und der Vorrang Erneuerbarer Energien, http://www.wiwi.uni-muenster.de/vwt/organisation/veroeffentlichungen/AFJLW-2010-Negative-Strompreise-und-der-Vorrang-Erneuerbarer-Energien-ZfE_final.pdf

[3] Angaben von E.ON Netz GmbH gemäß EEG §15; www.eon-netz.com/; Oktober 2008

[4] Angaben von EnBW Energie Baden-Württemberg AG gemäß EEG §15; www.enbw.com/; Oktober 2008

[5] Angaben von RWE Transportnetz Strom GmbH gemäß EEG §15; www.rwe-transportnetzstrom.com/; Oktober 2008

[6] Angaben von Vattenfall Europe Transmission GmbH gemäß EEG §15; www.vattenfall.de/; Oktober 2008

[7] BDEW Bundesverband der Energie- und Wasserwirtschaft e.V., http://www.vdn-berlin.de/bild_grundlagen_11.asp, Nov. 2007

[8] BERR (Department for Business Enterprise & Regulatory Reform), UK, North Hoyle Offshore Wind Farm 3rd Annual Report July 2006 – June 2007

[9] BERR (Department for Business Enterprise & Regulatory Reform), UK, Kentish Flats Offshore Wind Farm 3rd Annual Report January 2008 – December 2008

[10] BERR (Department for Business Enterprise & Regulatory Reform), UK, Barrow Offshore Wind Farm 1st Annual Report, 2006-2007

[11] BERR (Department for Business Enterprise & Regulatory Reform), UK, Kentish Flats Offshore Wind Farm 2nd Annual Report January 2006 – December 2006

[12] BERR (Department for Business Enterprise & Regulatory Reform), UK, Kentish Flats Offshore Wind Farm 2nd Annual Report January 2007 – December 2007

[13] BERR (Department for Business Enterprise & Regulatory Reform), UK, Barrow Offshore Wind Farm 2nd Annual Report, 2007-2008

[14] BERR (Department for Business Enterprise & Regulatory Reform), UK, Scroby Sands Offshore Wind Farm 3rd Annual Report January 2007 – December 2007

[15] Bofinger, Dr. Stefan et al., Studie zum Potenzial der Windenergienutzung an Land, Kassel, 2011 http://www.wind-energie.de/sites/default/files/download/publication/studie-zum-potenzial-der-windenergienutzung-land/bwe-potenzialstudie_final.pdf

[16] Brian Snyder, Mark J. Kaiser, Ecological and economic cost-benefit analysis of offshore wind energy, Renewable Energy 34 (2009) 1567–1578

[17] BTM Consult ApS, World Market Update 2007 – Forecast 2008 – 2012, Ringköping, DK, 2008

[18] Bundesnetzagentur genehmigt investitionsbudget in Höhe von 4,3 Mrd €, http://www.bmwi.de/BMWi/Navigation/Presse/pressemitteilungen,did=325556.html

[19] Bundesnetzagentur, Monitoringbericht 2010, Bonn, 2011

[20] Bundesnetzagentur, Monitoringbericht 2011, Bonn, 2011

[21] Case Study: "European Offshore Wind Farms- A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms", Final Report, Deutsche WindGuard GmbH, Deutsche Energie-Agentur GmbH (dena) University of Groningen. Gerhard Gerdes, Albrecht Tiedemann und drs. Sjoerd Zeelenberg, 2005

[22] Christopher Neil Elkinton, University of Massachusetts Amherst, Offshore Wind Farm Layout Optimization, 2007

[23] Colin Morgan, GARRAD HASSAN, Offshore wind turbines – Design and availability, 2008

[24] Contis-Seekarte Offshore-Windparks (Pilotgebiete) in der deutschen AWZ (Nordsee), Bundesamt für Seeschifffahrt und Hydrographie (BSH), Hamburg und Rostock, 2010

[25] Contis-Seekarte Offshore-Windparks (Pilotgebiete) in der deutschen AWZ (Ostsee), Bundesamt für Seeschifffahrt und Hydrographie (BSH), Hamburg und Rostock, 2010

[26] dti, UK, Capital Grant Scheme for the North Hoyle Offshore Wind Farm Annual Report: July 2004 – June 2005 Part 1

[27] dti, UK, Capital Grant Scheme for the North Hoyle Offshore Wind Farm Annual Report: July 2005 – June 2006

[28] E.ON UK, Capital Grant Scheme for the Scroby Sands Offshore Wind Farm Annual Report January 2005 – December 2005

[29] E.ON UK, Capital Grant Scheme for the Scroby Sands Offshore Wind Farm Annual Report January 2006 – December 2006
[30] Endbericht "Bewertung energiepolitischer Optionen für eine sichere, wirtschaftliche und umweltgerechte Energieentwicklung in Deutschland" "Analyse der Ursachen für negative Strompreise am 3./4. Oktober 2009 und möglicher Abhilfemaßnahmen" Studie im Auftrag des Bundesministeriums für Wirtschaft und Technologie 3.2.2010 http://www.ewi.uni-koeln.de/fileadmin/user/Gutachten/2010_Negative-strompreise_BMWI.pdf
[31] Energieleitungsausbaugesetz, http://www.bmwi.de/BMWi/Navigation/Presse/pressemitteilungen,did=303394.html
[32] European Wind Energy Association, Oceans of Opportunity – Harnessing Europe's largest domestic energy resource, 2009
[33] Fraunhofer IWES (Hrsg.); Abschlussbericht zum Forschungsvorhaben "Wissenschaftliches Mess- und Evaluierungsprogramm – Phase V"; Kassel, 2006
[34] Fraunhofer IWES (Hrsg.); Windenergie Report Deutschland 2008
[35] Gesetz über die Einspeisung von Strom aus erneuerbaren Energien in das öffentliche Netz (Stromeinspeisungsgesetz) Vom 7. Dezember 1990 (BGBl I S. 2633) (BGBl III 754-9) zuletzt geändert durch Gesetz zur Neuregelung des Energiewirtschaftsrechts vom 24. April 1998 (BGBl I S. 730, 734)
[36] Hoefakker B. ; OWEZ Shell, Offshore Windfarm Egmond aan Zee 4 years of Operation, 2010
[37] http://agmetalminer.com/2012/01/10/the-rare-earth-export-quota-in-2012-and-its-impact-on-metal-buyers-part-one/
[38] http://bdew.de/internet.nsf/id/3564E959A01B9E66C125796B003CFCCE/$file/BDEW%20Energie-Info_EE%20und%20das%20EEG%20%282011%29_23012012.pdf
[39] http://bundesrecht.juris.de/bundesrecht/ausglmechav/gesamt.pdf
[40] http://bundesrecht.juris.de/bundesrecht/ausglmechv/gesamt.pdf
[41] http://www.a2sea.com/Admin/Public/404.aspx (A2SEA)
[42] http://www.bdew.de/internet.nsf/id/DE_20111216-PI-Die-Verantwortung-waechst
[43] http://www.bard-offshore.de/de/projekte/offshore/bard-offshore-1
[44] http://www.bmwi.de/BMWi/Navigation/Presse/pressemitteilungen,did=348694.html
[45] http://www.bsh.de/de/Meeresnutzung/Wirtschaft/CONTIS-Informationssystem/index.jsp
[46] http://www.bine.info/fileadmin/content/Presse/Projektinfos_2011/Projektinfo_1711/ProjektInfo_ 1711_internetx.pdf
[47] http://www.bundesnetzagentur.de
[48] http://www.bundesnetzagentur.de/cae/servlet/contentblob/149950/publicationFile/3937/HintergrundNegativBoersenpreisepdf.pdf
[49] http://www.bmu.de/files/pdfs/allgemein/application/pdf/ee_in_zahlen_2011_bf.pdf
[50] http://www.dena.de/themen/thema-esd/projekte/projekt/ag-netzentwicklungsplan/
[51] http://www.duessel-wetter.de/index.php?option=com_content&view=article&id=985:rueckblick-sturm-orkan-starkregen-nordwesteuropa-0302-06022011&catid=79:startseite
[52] http://www.eeg-aktuell.de
[53] http://www.energieportal24.de/pn_91895.htm
[54] http://www.enbw.com/content/de/der_konzern/_media/pdf/eee-pdfs/referenzflyer_baltic1.pdf
[55] http://www.faz.net/s/Rub0E9EEF84AC1E4A389A8DC-6C23161FE44/Doc~E1A6A559028CF41F8AD3F57D0E13E3F4E~ATpl~Ecommon~Scontent.html
[56] http://www.forwind.de/forwind/files/forwind_a404einzelnklein.pdf
[57] http://www.fino3.de/joomla15/index.php?option=com_content&view=article&id=14&Itemid=278
[58] http://www.offshore-wind.de/page/index.php?id=4761
[59] http://www.taz.de/1/zukunft/wirtschaft/artikel/1/kunden-muessen-trotzdem-zahlen/
[60] http://www.transpower.de
[61] http://www.trianel-borkum.de/de/presse-und-service/winkraftwerk-borkum/details/article//erster-hammer-schlag-in-der-nor.html

[62] http://www.rechargenews.com/energy/wind/article306897.ece?cmpid=rss
[63] Informationen der 4C-Offshore Global Offshore Wind Database unter http://gis.oceanteam.net/offshorewind/
[64] Informationen der Deutschen Energie Agentur DENA unter www.Offshore-wind.de
[65] Informationen der Fino-Forschungsplattformen unter http://www.fino-offshore.de/ ; http://schiw.sf.hs-wismar.de/fino2/ ; www.fino3.de
[66] Informationen der Internetplattform "Windmonitor" unter www.windmonitor.de
[67] Informationen der Rave-Forschungsinitiative unter www.rave-offshore.de
[68] Informationen des Bundesamts fur Seeschifffahrt und Hydrographie unter www.bsh.de
[69] Informationen des Forschungsprojekt "Offshore-WMEP" unter www.offshore-wmep.de
[70] Informationen des Instituts für Meteorologie und Klimaforschung Forschungszentrum Karlsruhe GmbH – Forschungsbereich Troposphäre am Karlruhe Institut of Technology
[71] Informationen des Internationalen Wirtschaftsforum Regenerative Energien (IWR) unter www.iwr.de
[72] Informationen des Offshore Center Danmark unter http://www.offshorecenter.dk/offshorewindfarms.asp
[73] Informationen des Offshore-Windparks Horns Rev unter http://www.hornsrev.dk/Engelsk/default_ie.htm
[74] Informationen des Offshore-Windparks Middelgrunden unter http://www.middelgrund.com/
[75] Informationen des Offshore-Windparks Princess Amalia unter http://www.prinsesamaliawindpark.eu/en/bouwtechniek.asp
[76] Informationen des Offshore-Windparks Samso unter http://www.samsohavvind.dk/windfarm/
[77] Informationen des Offshore-Windparks Thornton Bank unter http://www.c-power.be/index_en.html
[78] Informationen des Wind Service Holland unter http://home.planet.nl/~windsh/offshore.html
[79] Informationen von alpha ventus unter www.alpha-ventus.de
[80] Ingenieurwerkstatt Energietechnik (IWET), Hamburg, 2009
[81] Jan Svenson, Wind Energy Consultant, Grontmij Carl Bro, 8 years O&M experience from Middelgrunden Offshore Wind Farm, EWEC 2008
[82] KPMG (Hrsg.); Offshore-Windparks in Europa – Marktstudie; 2007
[83] Lazaros P. Lazaridis; Royal Institute of Technology Department of Electrical Engineering, Economic Comparison of HVAC and HVDC Solutions for Large Offshore Wind Farms under Special Consideration of Reliability, Stockholm 2005 Middelgrunden
[84] NoordzeeWind, Operations Report 2007, 2008, www.noordzeewind.nl
[85] Poul Erik Ter-Borch; Risk management and ENERGI E2's responsibility during installation, commissioning, and operation and maintenance of Nysted Offshore Wind Farm
[86] Report "Experiences from the Construction and Installation of Lillgrund Wind Farm" Lillgrund Pilot Project, Arne Flodérus, Vattenfall Vindkraft AB, Mai 29, 2008
[87] Southern Winds, Summary Project Report 2007 – A study of wind power generation potential off the Georgia coast
[88] Stromnetze: Daten und Fakten, http://www.bmwi.de/BMWi/Navigation/Energie/Energietraeger/netze,did=292512.html
[89] Süddeutsche Zeitung, Netzbetreiber warnt vor Engpässen bei Windparks im Meer, 2011, http://www.sueddeutsche.de/wirtschaft/probleme-mit-offshore-windparks-nordsee-ohne-anschluss-1.1190286
[90] THE WORLD´S LARGEST OFF-SHORE WINDFARM, MIDDELGRUNDEN 40 MW, Jens H. Larsen Copenhagen Environment and Energy Office (CEEO), Austria 2001
[91] Vattenfall Danmark A/S, Kentish Flats Offshore Wind Farm Annual Report January 2006 – December 2006
[92] Valov, B. et al. "IWES-Concept 2010" for Offshore Power Transmission System 2020. DEWI MAGAZIN No. 37, August 2010. TenneT TSO GmbH
[93] Viehmann J, Sämisch H (2009). Windenergieintegration bei negativen Strompreisen. Energiewirtschaftliche Tagesfragen, 59, 49 – 51.
[94] WindPower Monthly Nov. 2011, S.12

FRAUNHOFER IWES

Fraunhofer IWES. The research activities of the Fraunhofer Institute for Wind Energy and Energy System Technology IWES cover wind energy and the integration of renewable energies into energy supply structures.

Fraunhofer IWES was founded at the start of 2009 from the merger of the former Fraunhofer Center for Wind Energy and Maritime Engineering CWMT in Bremerhaven and the Institute for Solar Energy Technology ISET e.V. in Kassel. The Fraunhofer IWES currently has a workforce of about 376 people.

The Fraunhofer IWES collaborates very closely with the Universities of Hannover, Oldenburg, and Bremen which make up the ForWind alliance. There is further close cooperation with the Universities of Kassel and Stuttgart.

Research areas. The research work of the Fraunhofer IWES covers all aspects of wind energy, including materials development, grid optimization, and energy system technology for all forms of renewable energy.

Key areas of research:

- Technology and operational management of wind turbines and wind farms
- Dynamics of wind turbines and components
- Component development for rotors, drive trains, and support structures
- Test and evaluation methods for wind turbines and components
- Environmental analysis of wind, sea, and seabed for utilization of wind energy and marine energy
- Control and system integration of decentralized energy converters and storage systems
- Energy management and grid operation
- Energy supply structures and system analysis

Test centers and laboratories. The Fraunhofer IWES has extensive testing and experimental facilities, laboratories, and equipment. In some areas our special expertise is enabling us to develop and introduce new test stands and test methods. These facilities coupled with the know-how of our scientists mean that the Fraunhofer IWES is able to offer its customers and partners research and development services and infrastructure which go far beyond the norm. Key facilities include:

- Competence Center for Rotor Blades
- Offshore ageing sites
- Wind measurement network and 200 meter measuring mast
- Laboratory for control systems for large wind turbines
- Experimental Center for Bioenergy Systems Engineering
- DeMoTec – Design Center for Modular Supply Technology
- IWES-SysTec – Test Center for Intelligent Grids and Electromobility
- Accredited test laboratories for converters and EMV
- Hessian Biogas Research Center

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